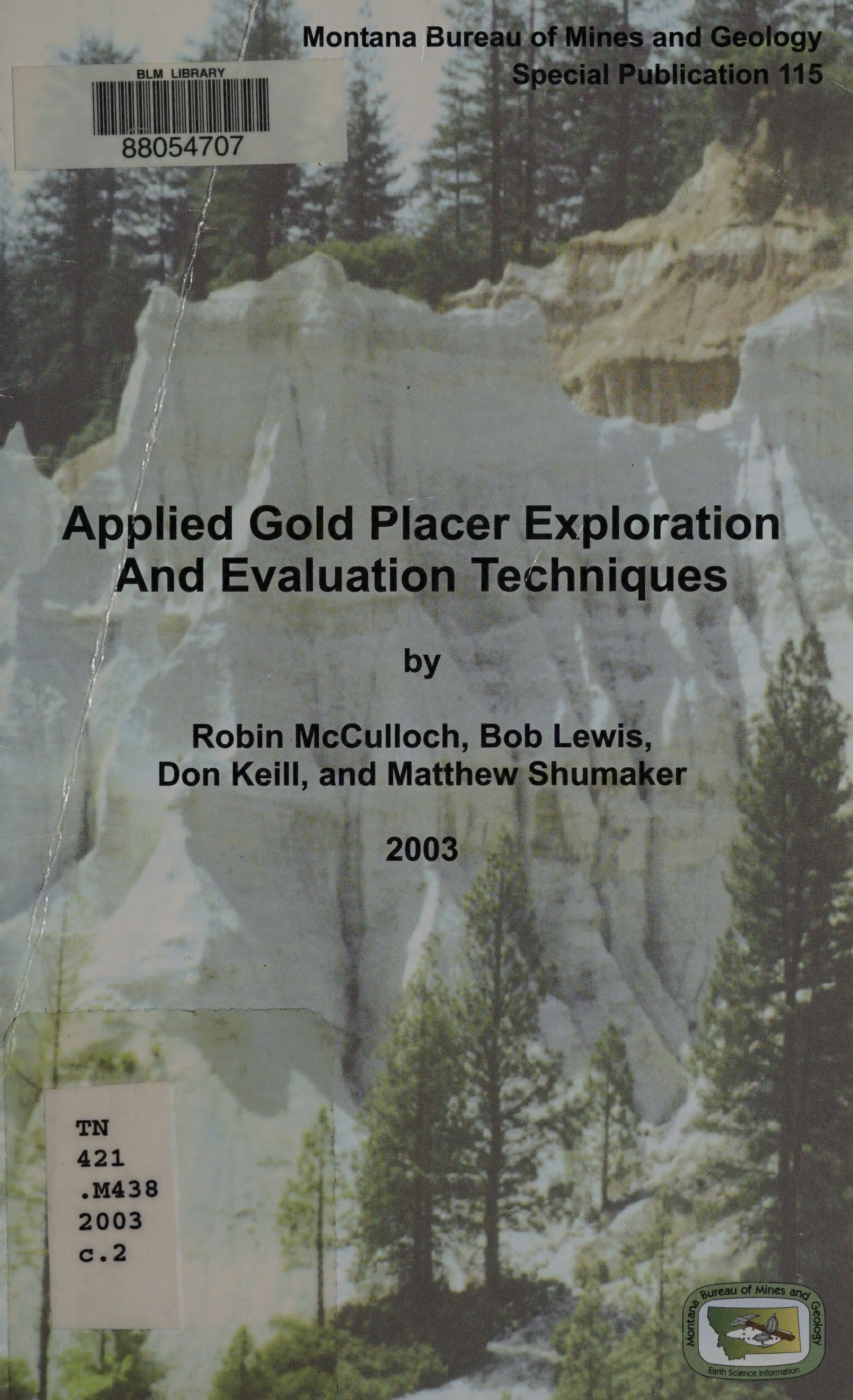
Montana Bureau of Mines and Geology
Special Publication 115





# Applied Gold Placer Exploration And Evaluation Techniques

by

Robin McCulloch, Bob Lewis,
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2003

*Cover Photo:* The high-wall in the North Bloomfield hydraulic pit near Nevada City, California. This historic mine is part of Malakoff Diggins State Park, an expansive example of hydraulic placer mining technology of the late 1800s. The mining techniques used here led to the Sawyer decision that banned direct discharge of hydraulickly mined waste (gravel and mud) into the streams and forced miners to use less destructive mining techniques. Within the pit are examples of both gulch (lag) and alluvial (transport) placer deposits.

Photo: Robin McCulloch

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# Preface

Precious metal placer mining has long been an industry dominated by small companies, individuals, or family miners. With the exception of bucket-line dredge operations, large companies have shown little interest in this aspect of the mining industry. Typically, most precious metal placer deposits lack sufficient volume to support the infrastructure of the larger companies. Part of that infrastructure is the research and analysis of the critical factors that control the formation of the deposits and the economic parameters of mining them. Of the data currently available, most were derived from large companies looking at the large yardage, low-grade deposits with dredge potential. The other types of placer deposits were summarily dismissed as "worked out or too small to be of interest"; however, neither of those assumptions are correct. These deposits are simply too complex to be easily explained and are time-consuming and expensive to evaluate. There also is no formal industry to support research and few trained professionals to undertake such a task.

This book represents the current best understanding of these complicated deposits. Most data were derived by interviewing experienced placer miners and then researching the miners' own questions. Additional knowledge of gold placers was drawn from the authors' experiences with property evaluations, patent exams, and validity exams. It became obvious in the course of those evaluations that the current "rules of thumb" regarding placers were either incorrect or were describing a different type of placer deposit from those encountered at most field sites. Existing literature on placers is almost entirely dedicated to the transport type of deposit, representing those deposits formed by "normal" processes. However, the type most frequently encountered in North America is the lag deposit, a residual product of erosion and deflation that differs considerably from the classic transport type of deposit.

The concepts and practices in this book represent several decades of experience and research by the authors. The final answers to remaining questions will only come with additional dissection of the deposits and careful observation.

This book was written to assist prospectors and evaluators of precious metal placers, providing guidance and enabling placer miners to succeed in their endeavors. It also will assist governmental evaluators in completing validity and patent examinations.

References to the pay, pay zone, or similar terminology refer specifically to gold unless stated otherwise, but many of the principles and concepts are applicable to any high-density minerals, including gemstones, some industrial minerals, metallic rock, sulfides, and other heavy metals such as platinum.

Precious metal placer mining has long been an industry dominated by small companies, individuals, or family miners. With the exception of bucket-line dredge operations, large companies have shown little interest in this segment of the mining industry. Typically, most precious metal placer deposits lack sufficient volume to support the infrastructure of the larger companies. Part of that indifference is the research and analysis of the critical factors that control the formation of the deposits and the economic parameters of mining them. Of the data currently available, most is derived from large companies looking at the large-yardage, low-grade deposits with dredge potential. The other types of placer deposits were generally dismissed as "worked out or too small to be of interest". However, neither of these assumptions are correct. These deposits are simply too complex to be easily explained and are time-consuming and expensive to evaluate. There also is no formal industry to support research and few trained professionals to undertake such a task.

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The concepts and premises in this book represent several decades of experience and research by the authors. The final answers to remaining questions will only come with additional dissection of the deposits and careful observation.

This book thus serves as basic prospection and evaluation of precious metal placers, providing guidance and enabling placer miners to succeed in their endeavors. It also will assist governmental evaluators in conducting validity and patent-examinations.

References in the text, pay streak, or similar terminology relate specifically to gold unless stated otherwise, but many of the principles and concepts are applicable to any high-density minerals, including gemstones, some industrial minerals, metallic rock, sulfides, and other heavy metals such as platinum.

# Chapter I: Placer Deposits

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# History of Placer Mining

Placer exploration activity in the western United States began as early as 1827 near Golden, New Mexico (Gardner and Johnson, 1934). Earlier mining was probably done by native inhabitants who did not mine enough material to leave evidence. In modern history, the most famous discovery of gold in this country was made by James Marshall on January 24, 1848, at Coloma, California. Marshall was constructing a water-powered sawmill and discovered gold nuggets in the tailrace. That discovery came too late to affect Mexico's decision to sell much of the southwest, including California, to the United States; in February of 1848, the United States paid 15 million dollars to Mexico as a war indemnity in exchange for its claims on the territory.

Placer mining provided an early incentive for people to explore and settle the western United States, and with the announcement of each new discovery came a new migration. The discovery of placer gold in California was significant because of the extent of the deposits and the large volumes of gold they contained. These volumes and the number of valuable properties dispelled the doubts of would-be miners and investors, justified the development of technology, and encouraged further exploration of the west. Had the deposits been small, it is unlikely that the industry and technology would have been developed.

When most miners came to the California gold fields (figure 1.1) there was no legal infrastructure. Although a leasing act had been developed as early as 1807 to address lode mines, it expired in the 1840s (Maley, 1985). In the resulting void, each camp or district developed its own set of laws and rules with which to administer the will of the local mining community. These rules were based on the Spanish Royal Code of 1783 and the customs of English miners from Cornwall and Devon. Federal

Figure 1.1. Four streams, with aggregate discharge of 2,500 miner's inches (about 62 $ft^3$ per second, dependent on the state—note appendix E). Material is washed through bedrock cuts to the sluices. North Bloomfield mines, Nevada County, California (Irelan, 1890).

law started to evolve in 1866, with a statute that allowed mining titles to be recovered through possessor actions.

Uniform laws governing placer claims did not exist until July 9, 1870, when the new Lode Law of 1866 was amended to include placer claims. The currently applied General Mining Law was established on May 10, 1872, with great influence from the lode and placer districts:

**Act of May 10, 1872; 17 Stat. 91 (Maley, 1985)**

This act replaced much of the 1866 and 1870 laws. The 1872 law declared "All valuable mineral deposits in lands belonging to the United States...to be free and open to exploration and purchase."

In addition to the lack of consistent rules and regulations among mining districts, knowledge of how to mine placers was initially limited. Technology improved rapidly, though, as ambitious miners developed low-cost procedures, and as the deposits waned from yielding vast riches to only covering daily wages. Many of the most experienced and knowledgeable miners moved on to other sites, continually exploiting the "easy gold" finds before moving on. As these miners moved quickly through the California gold camps, so did their expertise in placer mining technology, exploration, and production methods.

Mining camps in northern California and Oregon reported placer development in 1852; Nevada in 1857; Colorado in 1858; Idaho and Montana in 1862; Utah in 1863; South Dakota in 1874; and Alaska in 1886 (figures 1.2 and 1.3).

During the early 1860s, the United States was embroiled in the bitter and bloody Civil War. Thousands of people were displaced as businesses and homes were destroyed. The mining industry provided jobs for many of these people and created opportunities for businesses, with already established markets for those who wanted to supply the mineral industry. Placer mining, although a high-risk business, did not require much capital or unique skills. The potential to make a fortune existed for those with luck and a shovel.

There were advantages to being first, and clear disadvantages to being a latecomer. While some settlers came to mine the placers, still others mined the miners, and unfortunately a late arrival at a placer camp meant expensive supplies, barely enough gold to cover the expenses, and a harsh lifestyle of long days, short nights, and leaky tents.

Soon the most easily discovered and mined deposits were exploited. The remaining placer ground, though often just as rich, was difficult if not impossible to develop. By 1872, when gold was valued at $18.83 per troy ounce, most of the known placer deposits that could be profitably worked by individuals using surface hand methods were severely depleted (U.S. Bureau of Mines, 1993). Most placer districts were partially mined and abandoned by the miners within a 10-year period, and many districts completed the initial boom-to-bust cycle within only 2 years.

California became the incubator for the study of geology and the development of innovative mining engineering and techniques, as well as placer mining law. In 1867, methods for moving large volumes of material with water power were introduced in the California gold fields; however, high infrastructure costs forced small operators to band together to form companies capable of raising the necessary capital for labor and the construction of ditches. For example, ground sluicing was limited because it required large water volumes typically delivered by miles of ditches and flumes (fig-

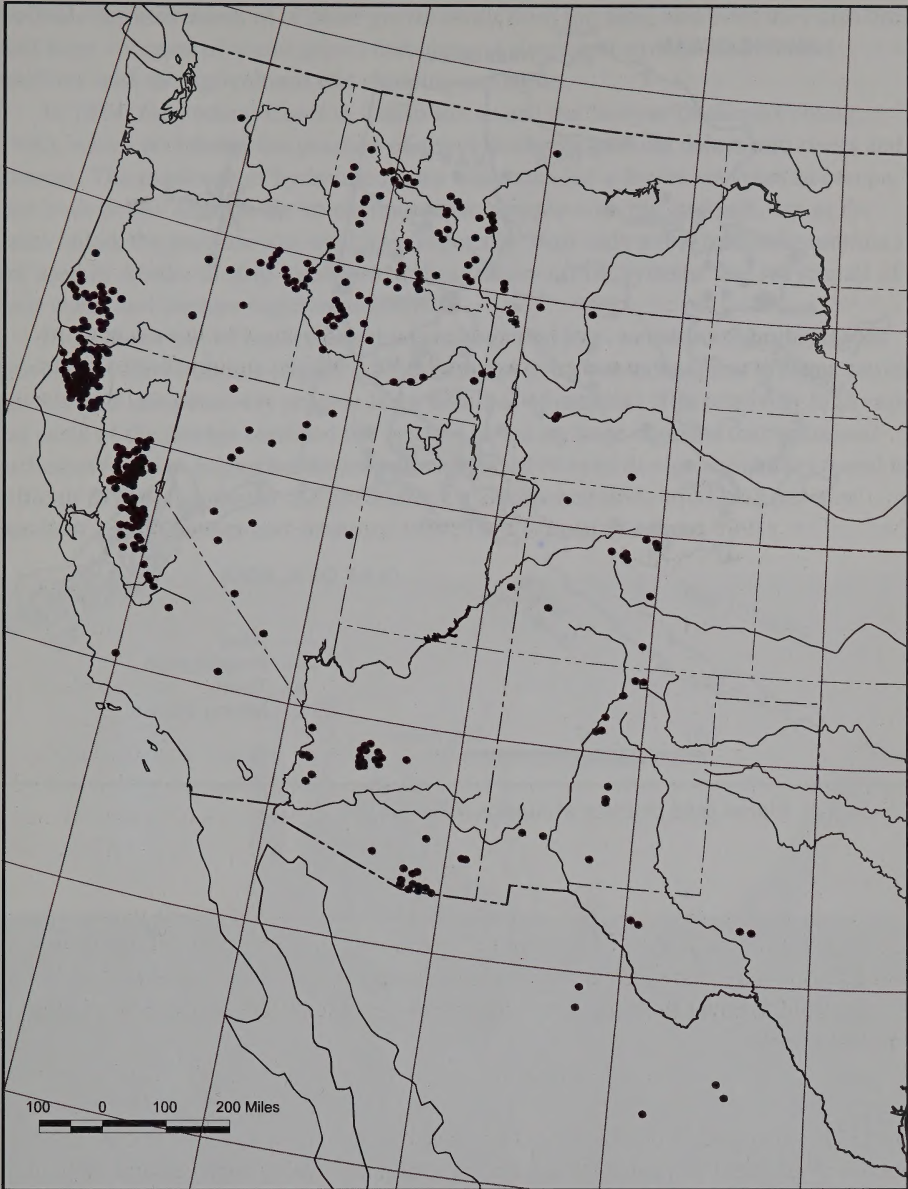



Figure 1.2. Location of placer-mining districts in western United States (After Gardner and Johnson, 1934).

ure 1.4). In response to this new market, many enterprising individuals formed ditch companies that provided water to the miners at a fee. Many of these ditches are still used to provide water for towns and agriculture. The method known as hydraulicking used smaller volumes at higher pressure, which eroded the placer gravel rapidly. This technique was flexible and efficient but required expensive pipe, ditches, and nozzles. It moved material faster and required less labor than ground sluicing. Both methods targeted low- to medium-grade bench and gulch placers with sufficient gradient to

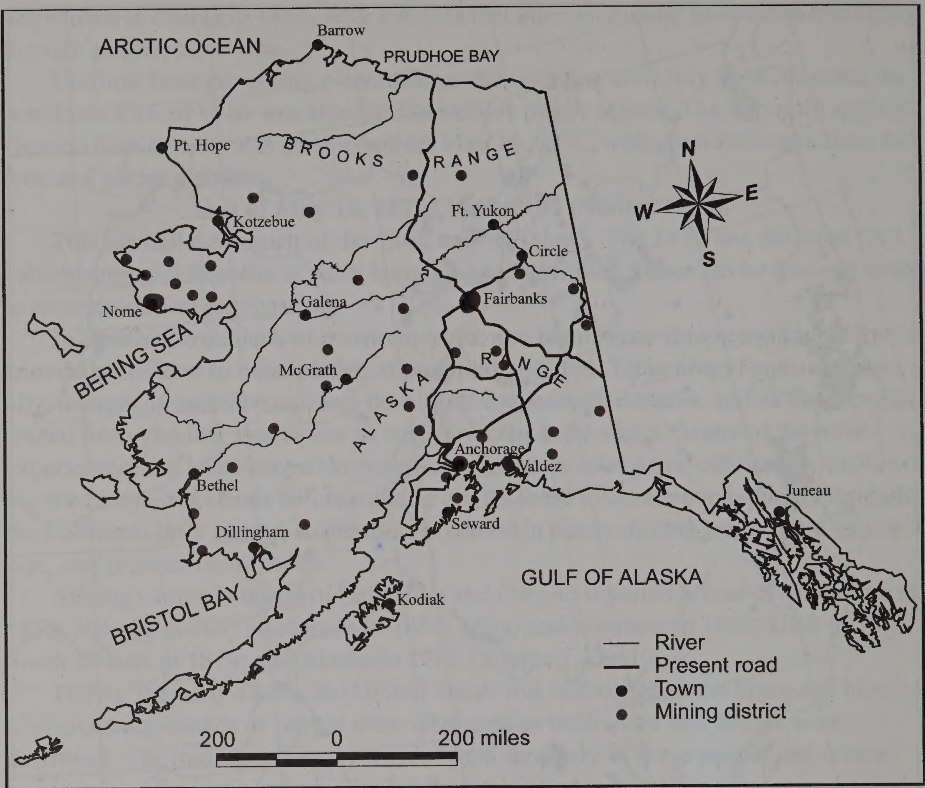



Figure 1.3. Placer gold districts of Alaska (After Cobb, 1970).

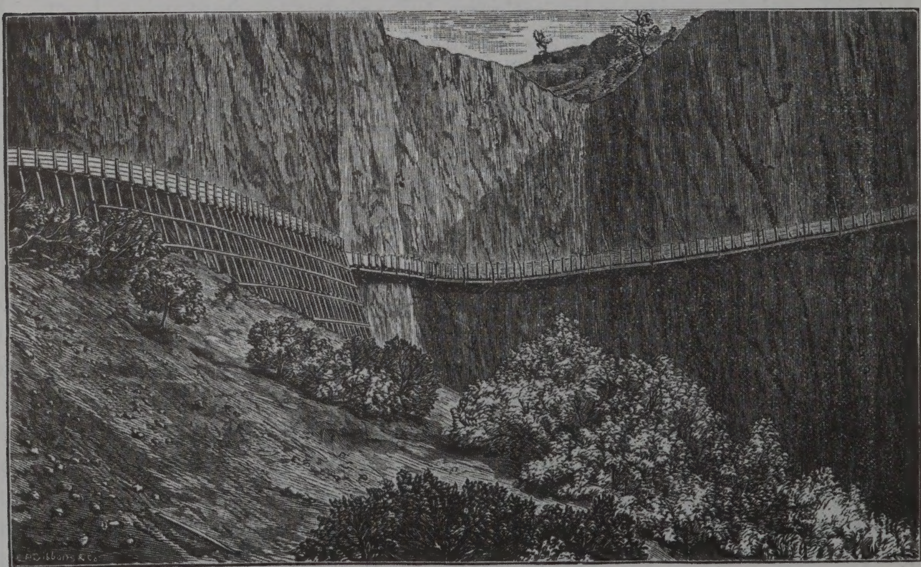


Figure 1.4. Bracket flume and trestle, Miocene company, California (Irelan, 1890).

facilitate the movement of washed gravel away from the face; however, they also created huge volumes of waste gravel that clogged rivers and streams and created conflicts with the agricultural and shipping industries.

In 1884, the Federal Court in California issued the Sawyer Decision (Young, 1946), which prohibited the practice of direct discharge of mine debris into rivers and streams. The existence of hydraulic mines was extended a few more years as companies built debris dams in the rivers in order to comply with the decision, but as the dams failed, the practice was used less frequently. Now only a few hydraulic monitors are used in Alaska to strip overburden; these mines utilize systems that recycle all of their water and capture fugitive sediment.

In 1898 the use of bucket-line dredges began on low- to medium-grade alluvial gravels in valley bottoms (figure 1.5). Compared to earlier techniques, dredges could quickly and inexpensively process large volumes of material. The relatively high capital costs of the dredge confined the method to use on large deposits that contained sufficient reserves to pay for the investment. By 1910 even dredge companies found it difficult to make money at the government's established price of $18.92 per troy ounce of gold (Gardner and Johnson, 1934; U.S. Bureau of Mines, 1993).

Figure 1.5. The *Fielding L. Graves* bucket-line dredge (Bannack, Montana), first in the United States.

Placer mining remained steady at low levels of activity until 1934 when the government raised the price of gold to $35.00 per troy ounce. Concurrent development of more advanced heavy equipment provided lower operating costs and higher production rates. As a consequence, many of the deposits that were previously deemed to be worked out and worthless yielded substantial profits.

Placer mining activity in general remained significant until 1942 when gold mining was labeled a non-essential industry by the War Production Board, Order L-208. Large-

to medium-size companies were ordered to cease operations and close down. This order did not affect as many mines as it could have if the order had been issued in 1941, when regulations, new taxes, and labor shortages had already eliminated many operations and diminished the profitability of those that remained (U.S. Bureau of Mines, 1943).

The order was rescinded in 1945 with the end of the war, but many operators discovered that with the combination of the fixed gold price at $35.00 per troy ounce and post-war inflation, most placer deposits were uneconomic. Only a few small operations, supported by the strength of 1930s exploration data and knowledge of mining, survived until the early 1970s, when the price of gold was allowed to seek an equilibrium on the international market.

The latest revival of interest in placer mining began in the 1980s when sustained gold prices nearing $400 per troy ounce combined with the availability of high-production heavy equipment to again make some placer deposits economically viable. Throughout the history of placer mining, deposits of specific grades have been mined as economics and technologies have allowed. The relationship is similar to the agricultural industry, in which produce is harvested after it has ripened. The placer industry has also harvested the ripe deposits; however, many more will mature with changes in economics and the development of affordable technology.

In the early years of placer mining, industry professionals witnessed a wide spectrum of deposit characteristics as they determined the viability of deposits, accumulating a tremendous resource of knowledge for future generations of miners and engineers. However, between 1942 and the 1980s, most of these professionals died of old age and their amassed knowledge was all but lost.

Currently, few mining schools offer instruction beyond an introduction to placer mining, much less educate students about evaluation techniques. Still, many of the techniques developed in the 1930s have survived and are now being used. Today financial investment in placer deposits is confined to experienced miners, small companies, and optimists with substantially more capital than practical understanding of placer deposits.

The purpose of this publication is to advance the body of knowledge about the nature and development of placer deposits and sample processing methods and to provide achievable exploration and evaluation standards for an all but forgotten industry.

# Placer Deposits

Placer deposits are defined in the 1968 U.S. Bureau of Mines Glossary of Mining Terms (Thrush, 1968) as: "earth, sand, gravel, or other rock or mineral materials transported by and laid down by flowing water." This definition confines the term placers to mean only material transported by water. The Dictionary of Mining, Mineral, and Related Terms (American Geological Institute,1996) offers a more updated definition for the term: "a deposit of sand or gravel that contains particles of gold, ilmenite, gemstones, or other heavy minerals of value." Because sand and gravel are typically associated with water transport, the new definition implies alluvial controls.

Case law has expanded the definition further to include material in place that has been processed by traditional placer processing methods (Maley, 1985). In light of previous legal decisions, precious metal placers may be more accurately defined as: "friable material containing minerals that can be concentrated by using conventional gravity techniques without benefit of crushing or grinding." Although this does not

encompass all situations, it allows for more flexibility and does not limit the definition of precious metal placers solely to those deposits that were transported by water, but expands it to include situations such as soft, highly altered, mineralized lode deposits. Although geologically the latter deposits are regarded as primary bedrock-hosted ores, many are exploited with the use of placer mining techniques; thus a continuum exists between hard-rock and placer deposits that has not been adequately addressed in the literature.

# Precious Metal Placer Systems

A precious metal placer system results from the interaction between various geologic processes and the underlying mineralogy, lithology, and geomorphology. Each of these geologic components contains critical elements that define the characteristics of each precious metal placer deposit within the system.

When considering a placer system, an evaluator must first identify all of the critical components. These include the lode source characteristics, including lithology, physical characteristics of the gold, alteration/weathering of the gangue, geomorphologic history (including paleoclimates), structural controls of the deposit and the source area, rock types and characteristics of the waste, the deposit's host bedrock and characteristics, and depositional environments. Each placer system may contain multiple lode sources and many different types of placer deposits.

## Lode Source

The precious metals found in placer deposits are initially part of a lode or hard-rock deposit that exerts very definite controls on any resulting placer. It is extremely difficult to understand a placer system without understanding the source(s) from which it was derived. Many of the characteristics of lode deposits and the resulting placers will be discussed in Chapter 2. However, it is important to note that even though many deposit models are discussed, there may be an equal number yet to be described. The information given represents a good foundation upon which to build greater future understanding rather than the end of the search.

## Release Mechanisms

Before a precious metal placer can form, some mechanism or situation must exist to make the minerals available for concentration. Most minerals commonly found in placers are formed at temperatures ranging from 50 to 500°C, under various pressures and chemical conditions (Park and MacDiarmid, 1975). Although the conditions necessary to free the minerals from the surrounding rock matrix can be divided into three distinctly different processes for the sake of discussion—physical release, hydrothermal alteration, and weathering—in the real world, the processes commonly overlap and may be impossible to completely distinguish. A few examples of each type are discussed below.

### Physical Release

Physical release may be as dynamic as the crushing and grinding caused by glaciers and fault movement or as subtle as the fracture of mineralized rocks by freeze–thaw cycles. Fault zones commonly form plumbing systems for mineralizing fluids and in turn become hosts for lode deposits. Fault zones cemented by silica may

develop into topographic highs, as silica-filled vein systems are particularly resistant to erosion. However, if the fault zone experiences recurrent movement after deposition, the brittle rock may be shattered or even ground to clay-sized gouge, both of which render the rock more susceptible to erosion. If fault movement exposes new rocks, then not only does the rock begin to break down, but these exposed rocks also experience accelerated degradation by gravity and other elemental processes. In the case of placer deposit formation these processes remove the waste and concentrate the valuable minerals. Other faults may be filled with relatively soft, easily eroded minerals and thus control the development of stream courses and valleys (figure 1.6).

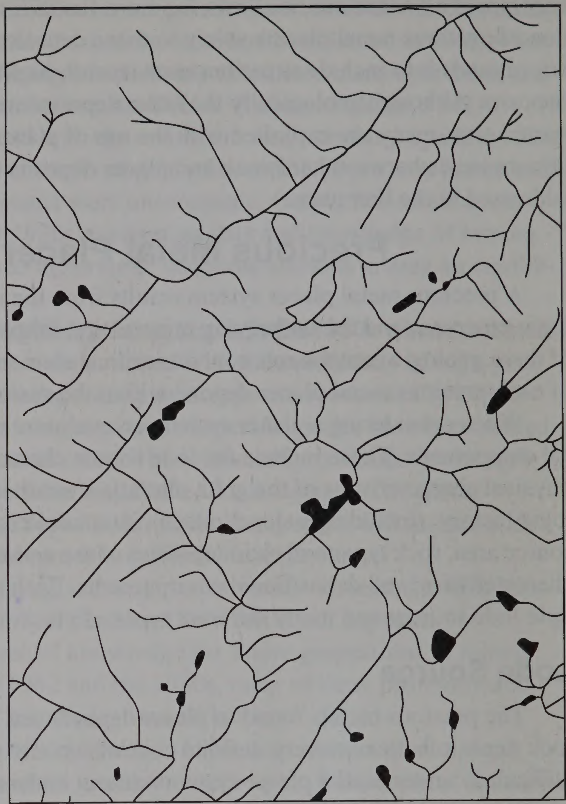


Figure 1.6. Structurally controlled rectangular drainage pattern (Thornbury, 1969).

Glaciers are bodies of ice that flow, with movement typically measuring somewhere between inches and tens of feet per year. The immense weight of the ice and the abrasiveness of rocks trapped within it work to gouge and grind bedrock. The eroded material is pushed along on the bottom and sides of the glacier, but little or no sorting of materials occurs. As glaciers retreat and the tremendous weight is removed, bedrock rebounds. During this release of pressure, differential stress may create fracturing of mineralized zones in the bedrock. Placer deposits may be formed if any economic minerals that may have been released during the erosional process are concentrated by water, wind, or gravity.

It is movement—in landslides, slumps, or talus slopes—accelerated by water and gravity that makes the minerals more susceptible to erosional processes and causes placer deposits to develop. In most cases, placer deposits are formed by a combination of these processes.

## Hydrothermal Alteration

Hydrothermal alteration of lode deposits is possibly the most significant method of preparation for placer development in nontropical environments. During deposition, the mineralizing fluid creates many chemical reactions among the ore minerals, host rocks, and ground water. Changes in chemistry, pressure, and temperature may result in both deposition and depletion of minerals in the surrounding rocks. Hydro-

thermal alteration is often observed in the rocks along faults and other plumbing conduits of mineralized systems.

Of the numerous types of alteration processes, many result in changes in the rock matrix that enable precious metals to be released more readily and enhance the opportunity for the formation of placer deposits. Most commonly, hydrothermal alteration changes competent rock into more easily eroded clays and fine white mica, which leads to the formation of topographic lows (figure 1.7). Alteration zones range in width from inches to miles. Many large alteration zones observed in Montana are 1,500 to 2,500 ft wide.

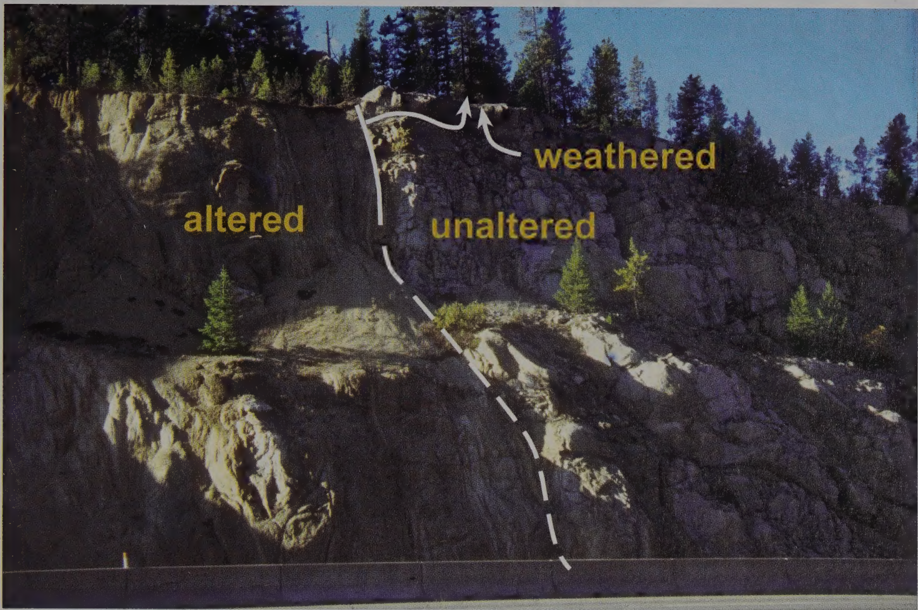


Figure 1.7. Contrast of altered, unaltered, and weathered rock near Butte, Montana.

By contrast silica flooding, a common hydrothermal alteration, tends to encapsulate the metals confined in the host rock. In this case large amounts of silica, often in the form of quartz, are deposited throughout the rock, filling earlier fractures with cementing materials. The result is a hard, tough rock that is highly resistant to erosion. These zones normally form topographic highs.

Some types of hydrothermal alteration may be confused with weathering. A highly significant difference is that hydrothermal alteration starts at depth within the rock and continues to the existing surface, whereas weathering starts at the surface and rarely extends more than a few hundred feet deep under tropical conditions. In temperate climates weathering rarely affects more than a few feet into the rock.

The depth of hydrothermal alteration is dependent on many variables, but hundreds of feet is not uncommon. In temperate climates the presence of hydrothermal alteration may have significant economic implications with regard to volume. Most mineable surface deposits are limited by economic factors. For instance, few surface placer mines extend deeper than 50 ft (figure 1.8) because of the cost of stripping the overburden.

Figure 1.8. A deeply buried placer on Elk Creek, Missoula County, Montana.

## Weathering

The term weathering incorporates a number of mechanical processes by which rocks are made physically smaller, including running water, frost wedging, ice-crystal growth, differential expansion by heating and cooling, and the effects of plants and animals. Weathering enhances the natural fracturing of the rock into smaller and smaller particles (Skinner and Porter, 1987) (figure 1.9), which releases the trapped heavy minerals. In addition to the mechanical influences, weathering includes chemical reactions: hydrolysis, leaching, and hydration. These actions chemically alter the rock-forming minerals into new minerals that are softer and more vulnerable to erosion. Thus the process builds on itself; the fracturing of the rocks due to physical weathering leads to higher levels of permeability that in turn increase the degree of chemical weathering (figure 1.10).

Depth of weathering is a function of many factors, including climate, topography, rock characteristics, and time. In some tropical zones, weathering may affect the rock for more than 300 ft below the surface. In colder climates or deserts, the same rock type may be weathered to only a few inches (figure 1.11).

Individual particles of heavy minerals are released through the combined effects of weathering, hydrothermal alteration, and physical release. For example, a gold-bearing quartz vein may fracture into large pieces of quartz containing minute amounts of gold. The specific gravity of each gold-bearing quartz particle would not be that much different from any piece of barren silica. Under such conditions, no placer concentration would occur because natural processes cannot segregate the gold-bearing particles from the barren quartz particles as long as the gold is a minor percentage of the total weight. Unless the gold is liberated from the quartz by some further action, little or no concentration can take place.


Figure 1.9. Weathering profile showing gradation upward from fresh bedrock (granite gneiss) to earthy regolith (Skinner and Porter, 1987, p. 208).

# Placer Development Mechanisms

Some placer deposits may be the result of a hydrothermally altered or weathered lode deposit that was originally formed at grades sufficient to support a profitable placer operation. The grades may be lower than that necessary to support hard-rock mining in the unaltered host because natural processes have already accomplished the release of gold particles from the surrounding matrix. This lessens the costs associated with mineral recovery.

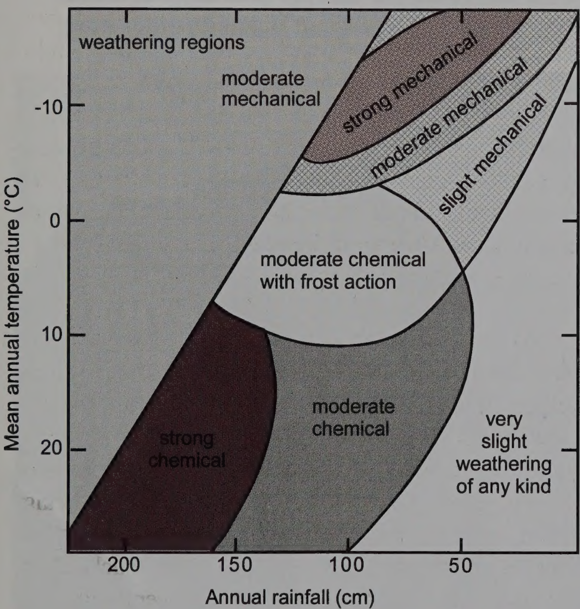



Figure 1.10. Climatic control of weathering process. Mechanical weathering is dominant where rainfall and temperature are both low. High temperature and precipitation favor chemical weathering (Skinner and Porter, 1987).

After the heavy mineral particles have been released from a rock matrix, some mechanism must concentrate them in order to create a placer deposit. This mechanism must be something that transports the heavy minerals or removes the associated waste material. Most commonly, the formation of a typical placer deposit depends on the forces of water, gravity, and/or wind.

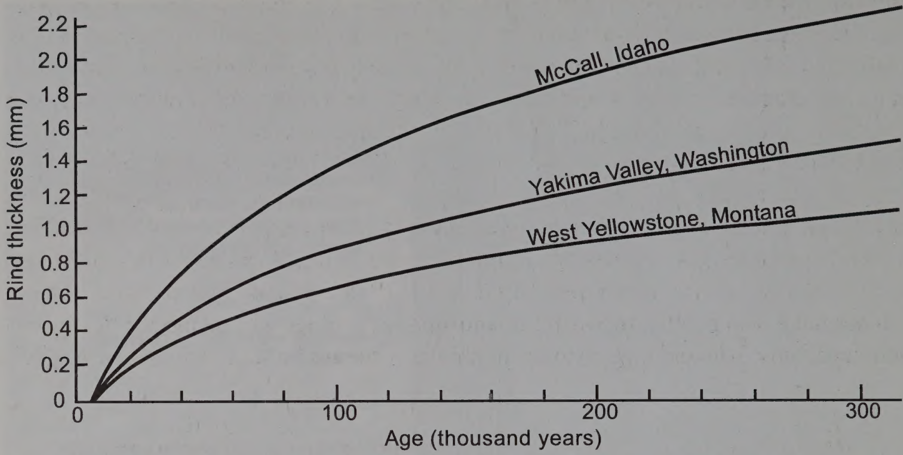



Figure 1.11. Change in weathering rates through time for three localities in the northwestern United States. Thickness of rinds on basaltic stones is plotted as a function of estimated or known age. Differences between curves probably reflect differences in the weathering environments among the sites. All show initial rapid weathering followed by a steady decrease in rate (Skinner and Porter, 1987).

If the released heavy minerals were all the same size, shape, and density, the maximum rate of concentration would exist with the wind or water velocity just below the critical level needed to move the heavy minerals. However, heavy minerals usually occur in a broad range of sizes and shapes, as do waste and gangue material. Thus the largest particles of materials of a particular density, such as gold, tend to remain close to the source as the lighter waste material and smallest particles are

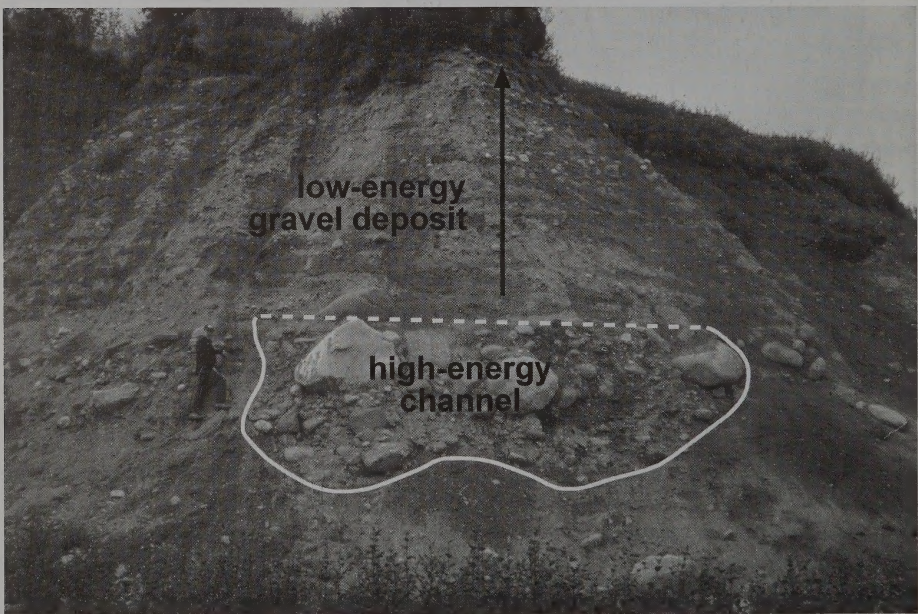



Figure 1.12. High-energy channel with a relatively low-energy deposit, Ferry Area, Alaska.

stripped away and transported greater distances prior to being deposited. Larger particles with large surface area to weight ratios may travel the same or greater distance as smaller particles of the same composition that have low surface area to weight ratios. At lower velocities, particles tend to become sorted on the basis of density, shape, and size. Under highly turbulent flow conditions, little sorting may occur in stream deposits (figure 1.12). Sorting may be done in a single event, but successive events may erode, transport, and redeposit placer material. During each event, additional sorting may occur, and heavy mineral concentrations may increase.

Only particles that are exposed to the eroding agent and can be moved at the prevailing velocity will be transported (figure 1.13). If the velocity of water will move a 2-in but not a 3-in pebble, then all 2-in and smaller pebbles will be moved down-gradient until only 3-in and larger stones remain as a stream bottom veneer. There may

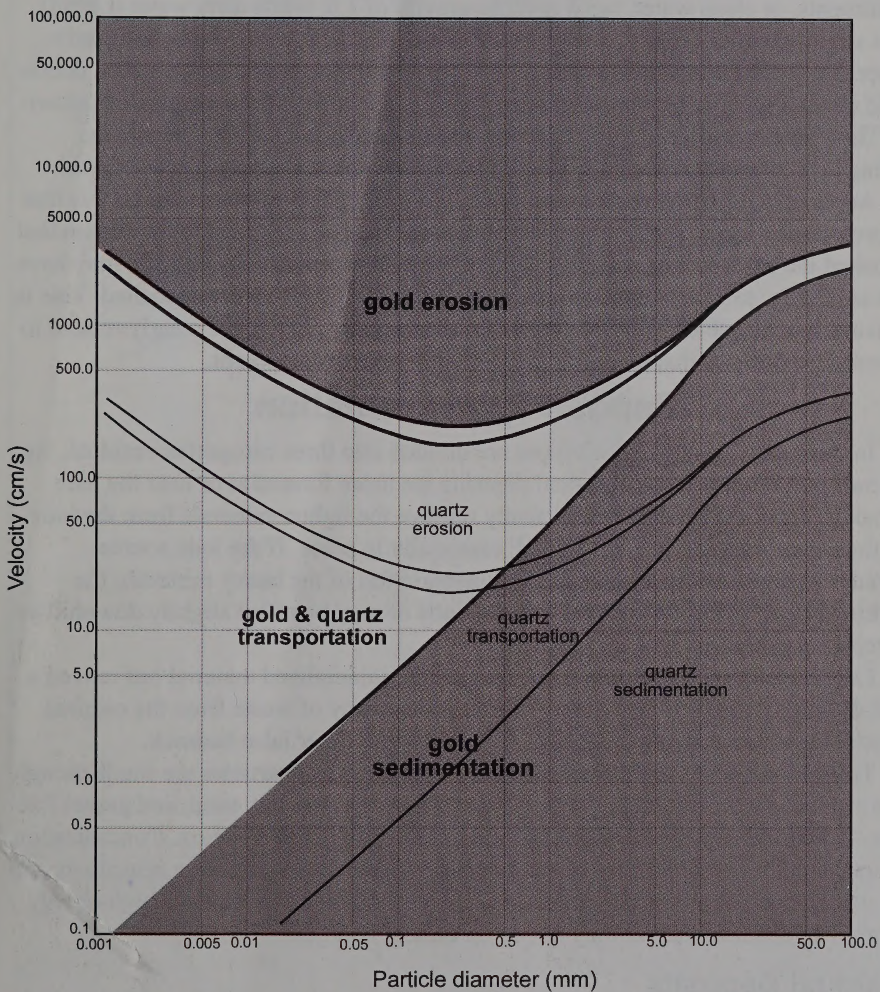



Figure 1.13. Erosion–transport–depositional criteria for small uniformly sized particles of placer gold and quartz in a fluvial system (modified from Hjulstrom, 1935, and Tourtelot, 1968).

be 2-in stones below them, protected by the overlying coarser layer, but until the velocity increases such that the 3-in pebbles are removed, the underlying materials are protected from erosion and transport.

By this process, the finer or lighter particles are preferentially winnowed out, resulting in an armored surface. Desert pavement is the equivalent result where eolian processes dominate. In contrast to the number of areas created by the effects of water, there are few areas of wind-influenced placers.

Stream channels are not uniform. Their gradients vary, and the localized velocity of the water will change to match the gradient. Carrying capacity of the water is greatly affected by local eddies and turbulence. Gold and larger rocks will often settle in the turbulent zones where velocities decrease.

An effect seldom researched in high-velocity areas is the settling rate of the transported load in a dense solution. Water with no suspended solids or dissolved constituents, or clean water, has a specific gravity of 1.0, while dirty water (turbid) has a slightly higher density; a slurry such as a debris flow would be significantly higher. For example, a slurry containing 50 percent water and 50 percent rock debris could attain a specific gravity of greater than1.5 depending on the suspended materials. This density combined with viscosity and lack of turbulence can negate the settling rates of most particles, including large boulders and heavy pieces of gold.

Another important consideration critical to understanding placer deposits is that the present-day location of the stream or drainage may be unrelated to the stream that deposited the placers. The current environment, and especially the climate, may have little similarity to what conditions were like when the placers were deposited. This is particularly noticeable in the western U.S., where many placers are clearly related to geomorphic surfaces that preceded present landscape development.

# Deposit Type Formation

In this report, placer deposit types are divided into three categories: residual, lag, and transport (figure 1.14). Residual deposits are those formed at or near the lode deposit as erosional processes selectively remove the lighter minerals from the lode and the heavy minerals are left behind, essentially in place. If the lode source degrades in place, without appreciable transportation of the heavy minerals, the resulting placer will form directly over the lode or may be offset slightly downhill as the result of processes such as soil creep.

Lag deposits are placer deposits in which the mineralized material has moved a short distance from the lode source. The stripping away of waste from the original material has created a placer deposit on or near bedrock or false bedrock.

Transport deposits are formed when the heavy mineral particles are small enough to be eroded and transported by water—along with the clay, silt, sand, and gravel fractions—a significant distance from the lode source prior to redeposition. Concentration occurs when the velocity of the water decreases and the heavy fraction selectively settles out. The values are usually in multiple layers and relate to multiple high-energy events. The deposits may or may not be on or near bedrock.

## Residual Deposits

Residual deposits (table 1.1) have most commonly been depicted as forming on ridge tops. However, field experience shows that they are certainly not confined to ridges. Because residual deposits are formed in place as the lighter waste materials

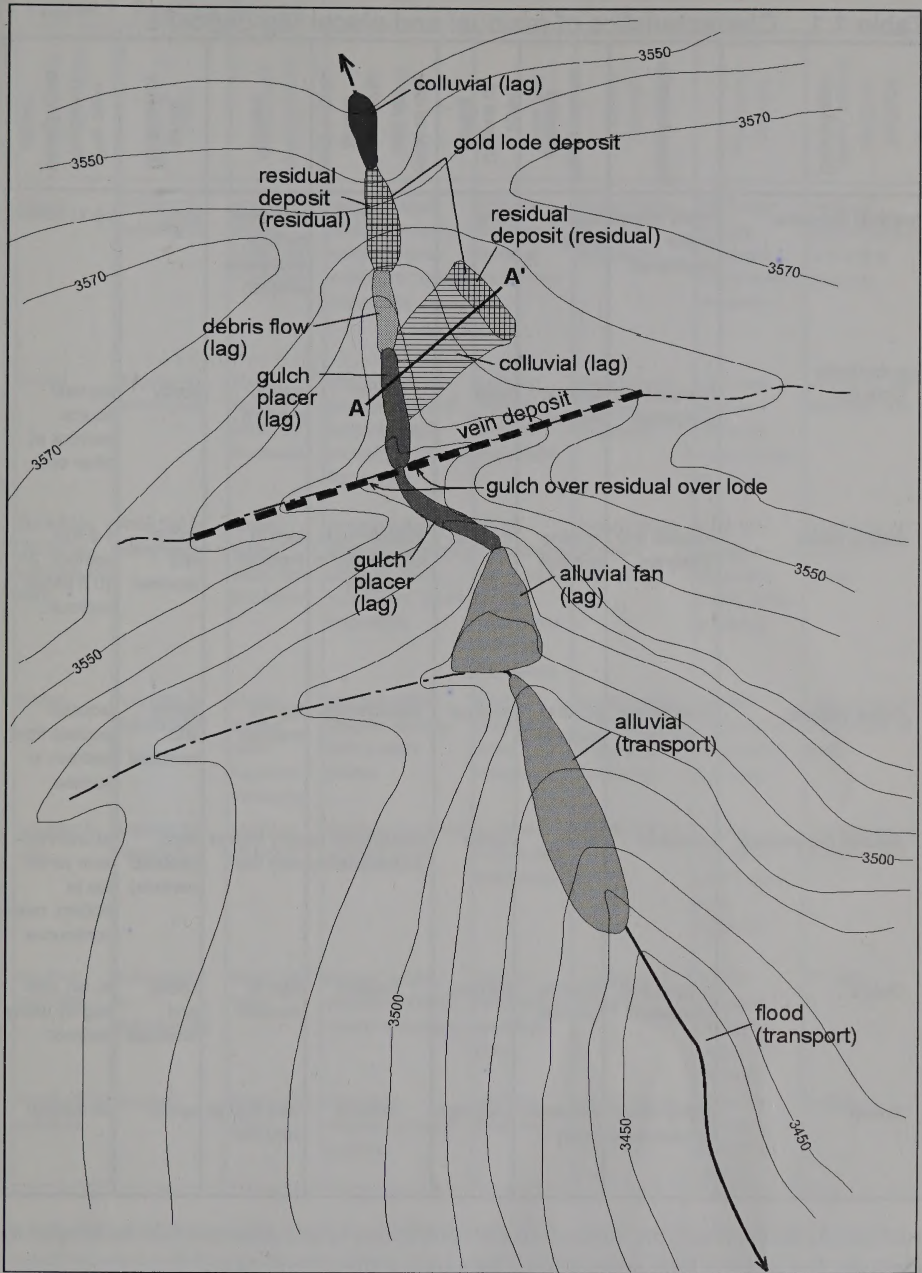



Figure 1.14. Deposit types in an idealized placer system.

are removed from a lode deposit, residual placers can potentially form anywhere a lode deposit subcrops.

Unless the deposit is buried by barren overburden or debris, it characteristically has mineral values from the grass roots downward. In fact, the richest values often exist within the first few feet of the surface and gradually decrease to the lode deposit

Table 1.1 Characteristics of residual and placer lag deposits

| Deposit type | Bedrock quality | Placer volume potential | Degree of sorting | Ratio of clay and silt compared to gravel components | Values | Grade consistency | Pay zone location in stratigraphic column |
|---|---|---|---|---|---|---|---|
| **Residual deposits** | highly altered and/or weathered | large to small | none | high | high near surface; decreases w/depth | spotty | top to bottom |
| **Lag deposits** | | | | | | | |
| **Colluvial** | fractured but competent | small to medium | none | high | high to medium | spotty | top near source; bedrock at other end |
| **Debris flows** | variable and unrelated | small to medium | minimal | medium high; well packed in matrix | high to medium | spotty and localized | 1-2 ft in bedrock; 2-10 ft above bedrock |
| **Pulse placers** | variable and unrelated | small to medium | minimal | medium high | high to medium | spotty and localized | isolated pockets from bedrock to surface |
| **Alluvial fan placers** | unrelated | large | varied | medium low to unpredictable | very high to very low | none (isolated pockets) | at unpredict-able zones; top to bottom; rarely continuous |
| **Gulch** | ragged and competent | small to medium | minimal | medium | high to medium | spotty and localized | in, on, and slightly above bedrock |
| **Eolian** | highly altered or weathered | extremely small | very high | minimal | very high to very low | spotty | on surface |

surface. At that surface, the values and concentrations of ore minerals will be similar to the lode, but like the lode deposit, may be very localized and spotty.

The bedrock usually exhibits hydrothermal alteration and possibly weathering; the gold particles are typically ragged and coarse and reflect the mineralogical character of the lode source. The contact between the altered lode and the residual placer is commonly so indistinct that often the evaluator will not recognize it until many vertical feet of the lode have been exposed.

The gangue material is commonly angular to subangular and, in the case of a hydrothermally altered lode source, contains large portions of clays that do not exhibit

Table 1.1—Continued

| Waste particle size distribution | Waste particle shape | Gold/crystal characteristics | Gold shape | Gold chemistry | Industrial mineral characteristics | Accessory minerals | Heavy mineral transport distance |
|---|---|---|---|---|---|---|---|
| broad | angular to subangular | sharp edges; clear; no fractures | ragged edges; angular smooth surface; many inclusions; quartz fragments | uniform fineness; mineral inclusions | broad range of sizes; angularity | may see sulfide minerals; many softer minerals | vertical; inches to feet; horizontal minimal |
| broad | angular to subangular | sharp edges; clear; no fractures | ragged edges; angular; smooth surface; many inclusions; quartz fragments | uniform fineness; mineral inclusions | broad range of sizes; angularity | may see sulfide minerals; many softer minerals | inches to few hundred feet |
| boulders 30-50%; cobbles 20-90% | rounded to subangular | sharp edges; clear; few fractures | ragged edges; angular; smooth surface; many inclusions; quartz fragments | some enrichment on rims or silver depletion; mineral inclusions | broad range of sizes; angularity | may see sulfide minerals; many softer minerals | hundreds of feet to < 5 miles |
| broad | rounded to subangular | sharp edges, clear; frequent fracturing | ragged edges; smooth surface with impact marks | limited change from source | broad range of sizes; angularity; fracturing | exhibit fractures as opposed to grinding | short distance (hundreds of feet) |
| boulder to clay | angular to rounded | sharp to abraded | typically flattened; smaller sizes | leached edges; few inclusions | smaller sizes | oxides; crystals; small sizes; hard minerals | few thousand feet to miles |
| boulder; cobbles | subangular to subrounded | sharp and clear | ragged edges; smooth surface; quartz inclusions | uniform fineness to enriched rims | coarse and angular | sulfide minerals possible; many soft minerals | <1 mile |
| small silt to cobbles | angular | sharp and clear | coarse to angular; smooth surface | uniform fineness | broad range of sizes (majority larger) | dependent on size and specific gravity | inches |

water-lain characteristics such as stratification. The clays commonly contain unaltered minerals that give them a gritty texture. Sulfides may also be encountered, and imprints of crystal faces are visible on the gold.

The boundaries of these deposits are difficult to locate visually, especially if the unaltered bedrock is never encountered. Unless the deposit is significantly exposed during excavation, only detailed sampling and mapping (good field notes are critical) may indicate the limits of this type of deposit. Many times the evaluator may only start to suspect the existence of a residual placer during sampling, especially if the sampling conditions include wet, caving holes and visual clues are not diagnostic.

Usually interpretations will not be confirmed until further evidence from the sample results is available. Indicators of a residual placer include clay, sulfides, angular gold specimens, and specific mineral associations in the concentrate that would commonly be found in the source-lode deposit types.

Residual placer deposits can be quite extensive in tropical environments where weathering is more intensive and high precipitation rates may more effectively strip the waste. In temperate environments, the minerals are most often liberated by hydrothermal alteration. In desert areas, a residual placer may develop as a thin veneer on top of an altered lode deposit through eolian deflation. Some veins, or fault zones, may range from 200 to 2,000 ft wide and can be traced for miles. Skarns formed along the contact of intrusive bodies and carbonate rocks can be similarly extensive. However, the mineralized zones within these source areas are normally small and localized. Extensive examples of residual placers are supplied by Boyle (1979). On a worldwide basis, significant production can be attributed to these deposits.

## Lag Deposits

Lag deposits (table 1.1) exhibit poor sorting, a broad range of rock sizes, angular to subrounded particle shapes, localized high-value concentrations of gold with poor predictability of location and grade, and a higher concentration of larger than smaller sizes of other heavy minerals. Similar to residual deposits, the gold particles typically exhibit sizes spanning the range of those in the lode source. They are crystalline, angular, flat, and shot-like or wire-like in shape and exhibit little rounding, folding, and/or surface deformation.

The placers are often overlain by well-sorted, barren alluvial gravels that represent the effects of annual erosional processes that exist between the periods of precipitation extremes. Normal surface water flows do not have the velocity necessary to re-erode these deposits, but are successful in depositing barren gravel over them.

### Colluvial

The term colluvium is applied to any loose, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited by rain wash, sheet wash, or slow, continuous downslope creep that collects at the base of a gentle slope or hillside (Bates and Jackson, 1980). Differential movement allows the heavy mineral grains to "sink" within the mass, where they eventually concentrate on top of the bedrock, in fractures, behind resistant structures, or along undulations in the bedrock surface (figure 1.15). Through this concentration process, the lighter gangue material is stripped away from the precious metal particles, thus enriching the overall grade of the materials left behind. During movement heavy minerals have a tendency to be sorted by particle size; the larger particles are left closest to the source.

Colluvial deposits typically have angular to subangular rock fragments, little or no sorting, erratic medium- to high-grade values, and high ratios of soil and clay to rock particles in the samples. These deposits rarely contain large volumes, and sample intervals must be closely spaced for adequate evaluation of the deposit potential, since the high-grade zones mirror the ore shoots within the lode source.

### Debris Flow

Debris-flow deposits result from a mass movement of lode deposit material triggered by unusually high periods of precipitation. Significant hydrothermal alteration

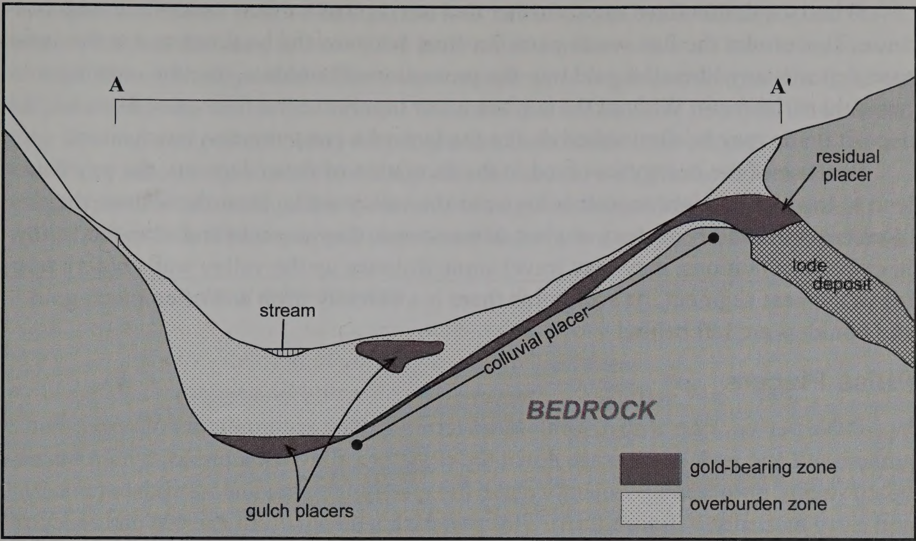



Figure 1.15. A schematic cross section of placer types A–A' shown in figure 1.14.

of the lode source is necessary to prepare the lode deposit for selective release of mineralized material.

Often debris flows occur in a valley or gulch as a channelized flow and have narrow pay zones that have high, localized values. There is a high percentage of clay in an unsorted angular to subangular boulder/cobble mass. The clay-rich matrix between the boulders typically varies in color from red–brown to red, orange, or yellow–orange. The economic portion of these deposits is typically confined to the first few feet above bedrock and into the first 2 ft of fractured bedrock. The bedrock tends to collect gold along rough surface textures and resistant outcrops; in fractures, pockets, and fault-controlled depressions; and in places where topographic flattening of the bedrock gradient occurs.

A mechanism of formation may include a significant increase in saturation of the altered material that may be accompanied by water flow along the unaltered boundaries of the lode. At some point the material loses critical cohesion, and the altered material slides rapidly toward the main drainage. As the debris flow reaches the valley bottom, it may partially restrict the surface water flow while still moving downstream. Eventually the water will flow over the top of the debris flow, stripping the fine material off until it exposes a boulder pavement where the mass is armored against erosion.

During dewatering of the flow, fine material and any small gold particles are carried to the surface where they are stripped off by higher velocity surface water flows and deposited miles farther downstream. During this time, the coarser gold particles settle to the lower portion of the flow, and some exit the flow and collect along the surface of the bedrock.

The density of the flow is variable but may run as high as 80 percent solids. The clays originally contained in the lode deposit alteration aid in maintaining the flow density, retard infiltration of surface water, and provide a lubricated sliding surface on the bottom.

When the debris flow stops, further dewatering and surface water flow may continue. This erodes the fine waste particles from between the boulders and at the same time deposits any liberated gold into the protection of boulders, thereby creating a two-fold enrichment. Without the surface water to remove the fine waste material, the deposit grade may be diminished due to the lack of a concentration mechanism.

Because of the energy involved in the formation of these deposits, the pay zones tend to travel in straight segments between the valley walls. Near the source, they often cross the valley at sharp angles; downstream, they are subparallel to the valley. In extreme conditions, they may travel some distance up the valley walls before turning in the next segment. At such turns there is a velocity drop and often much gold and boulders are left behind.

## Pulse Placers

Pulse placers start with a rapid, short-term, surface accumulation of water that gathers soil and rock as it rushes down the slope or valley. This turbid, hyperconcentrated stream flow rushes violently down the gullies, eroding unconsolidated material and carrying it along (figure 1.16). This material is then partially sorted and redeposited by size and shape as the force and flow of the stream subside. These events are common in deserts because of both the lack of vegetation necessary to retard the water and a resistance of the soil to "wet" or absorb water after periods of intense dryness. They also occur in temperate climates after cloud bursts.

These placer deposits are formed by repetitive reworking of the gravels in successive short-term high-precipitation events. Low-velocity flows of water that would normally remove the silts and sands are of such short duration that the gravel deposits remain largely unsorted and heavy with silt. Although the surface may appear to show sorting, a trench cut through the deposit would reveal both sorted and unsorted material.

Figure 1.16. Results of a desert flash flood, southeastern Arizona (Photo by Diane Drobka).

Between events in hot climates, the heat of the desert bakes the deposited clays into a hard pan that may act as a false bedrock or surface armor as it is not easily eroded. The shallow ground-water evaporation may leave subsurface caliche (calcium carbonate) layers, which then cement sediment and create false bedrock. The caliche may also cap and protect older, deeper placers from further reworking.

Pulse placers are characteristically discontinuous, with erratic values. The gangue particles may range from rounded to angular, depending on their location within the system. The pay zones may be on bedrock but are just as likely to be found

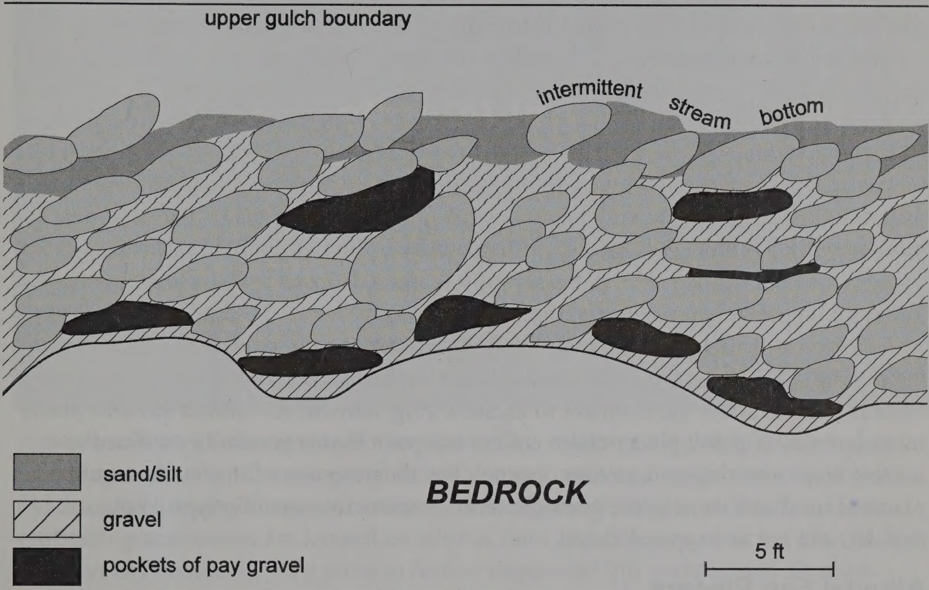



Figure 1.17. Longitudinal section of a pulse placer.

isolated in discrete, discontinuous pay pods (figure 1.17) perched at random elevations above bedrock. These pods may be the result of turbulent areas in the stream bottom. Although the grades of the pay pods may be quite high, the pods are usually thin. It is unlikely that sufficient pay gravels will have accumulated in these pay zones to support commercial mining, because the depth of reworking is limited by the duration and intensity of the flows and the erodability of the streambed. The accessory heavy mineral particles (zircons, apatite, etc.) may exhibit angularity that is enhanced by fracturing. These high-energy systems tend to promote much tumbling and rolling of the rocks, which create compression fractures among the particles.

The highest potential for valuable mineral concentration may exist at the topographic flattening of the gradient or widening of any confining valleys or gullies.

## Gulch Placers

Gulch placers are characterized by narrow, confined drainages with steep gradients and numerous boulders. They are very high-energy lag systems, like debris flows, but do not normally contain the same volumes of clay. In most cases, the bedrock has been scoured nearly smooth, probably prior to deposition of the placer. These placers tend to have an undulating gradient caused by structural controls or differentially ero-

sion-resistant rocks. Within the drainage are boulder clusters with poorly sorted cobbles and finer material backed up behind them that act as natural riffles.

The overall thicknesses of these deposits are normally less than 10 ft from the surface of the deposit to bedrock. The heavy minerals in the deposit tend to be larger size particles. The grades can be quite rich, but are spotty with smaller volumes of resources. Pay zone widths are usually narrow. Average thicknesses of the pay zones range from a few inches to a few feet and are usually on bedrock. The gold may be concentrated within pockets along the drainage, especially if the bedrock is undulating and smooth. A gulch placer is usually difficult to evaluate because of the physical restrictions of the drainage, erratic nature of the deposit, and bonanza-type pockets.

Heavy mineral particles in these deposits normally exhibit little visible physical change from the source area. Most of the waste particles are subangular to subrounded and appear to have more wear from impact with rocks than abrasion from rolling and tumbling in water.

Without the aid of today's equipment, most of the miners of the past were challenged by the steep terrain and large boulders. Consequently, of the deposit types, these primitive placers contain a significant share of partially mined resources. Because of their limited size, these partially worked deposits are now the targets of individual miners, as opposed to larger companies.

The term "gulch placer" has developed different meanings over the years. In legal terminology, it is a type of mining claim, staked and recorded by metes and bounds so as to allow the claimant to locate a long, narrow, sometimes sinuous placer mining claim. A gulch placer claim covers a deposit that is generally confined to a narrow area centering on a stream channel. For the purposes of this book, a gulch placer is used as a descriptive geologic term. It refers to a specific type of placer deposit, and not to a type of claim.

## Alluvial Fan Placers

Alluvial fans form when a stream or gulch exits a steep, narrow valley and enters one with a flatter gradient (figure 1.18). A stream flowing across this gradient inflection transports coarse material to a point at which the valley floor flattens; there it deposits its load at the velocity change. Over time this depositional zone forms into a fan shape, which builds until the gradient between the gulch mouth and valley floor is shallow enough to decrease the carrying capacity of the water. A large proportion of the material forming the fan may have been moved during catastrophic events, such as those described in the section on pulse placers, rather than during normal stream flow. During these events, there is enough velocity present in the stream to erode and transport gold along with large rocks.

The stream that forms the fan is not confined, but instead wanders back and forth, first depositing its bedload and then re-eroding it. The fan usually contains both sorted and unsorted gravel, with angular to rounded particles that range in size from boulders to clay.

Alluvial fan placers are composed of a group of stacked, gold-bearing gravel deposit segments (figure 1.19). Some portions have been covered with waste, many have been partially removed, and others have been enriched. The deposit characteristics are dictated by the lode source and each precipitation event, but often the depositional energy level is similar to that of the gulch or pulse placers. The duration of the events


varies broadly with the climate of the region. This makes prediction of grade and volume very expensive, if not impossible, as each pay zone segment is narrow and thin. Grade control during mining is extremely difficult and time-consuming. Few if any profitable placer mines are located on alluvial fans. Bajadas, or coalescing alluvial fans in desert environments, only serve to further compound this complicated situation.

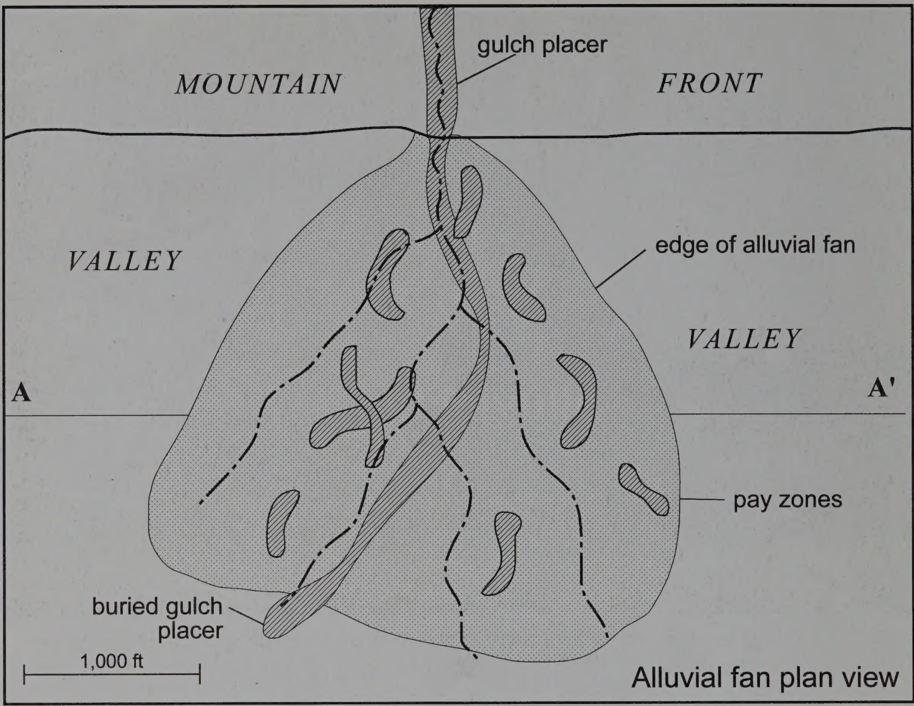
## Glacial Placers

Despite folklore, glaciers generally do not form placers. Instead they tend to push or smear debris and contained heavy minerals over broad areas and mix extensive amounts of unsorted material. The resulting deposits exhibit little or no sorting and contain abundant clay or rock flour (figure 1.20). Deposits that develop in association with glaciers are typically alluvial or gulch placers formed from outwash that represents a reworking of glacial drift by streams.

## Eolian Placers

Eolian placers are residual deposits in which the fine, light material was removed by wind rather than water (figure 1.21). The deposit must also have been weathered and/or altered in such a way that the matrix of the deposit is reduced to a size fraction that the wind can remove. Otherwise, after the fine materials are removed, the coarse fraction will armor the deposit and protect it from further erosion and concentration.

The potential for large deposits of this type is minuscule and is of legitimate interest only to small operators and hobbyists. Heavy metal concentrations exist only on the surface and are usually quite shallow, not exceeding a few inches in depth. These minerals may represent the majority of the coarse fraction. Accessory minerals are proportionally greater in volume and thereby decrease the deposit's economic potential.



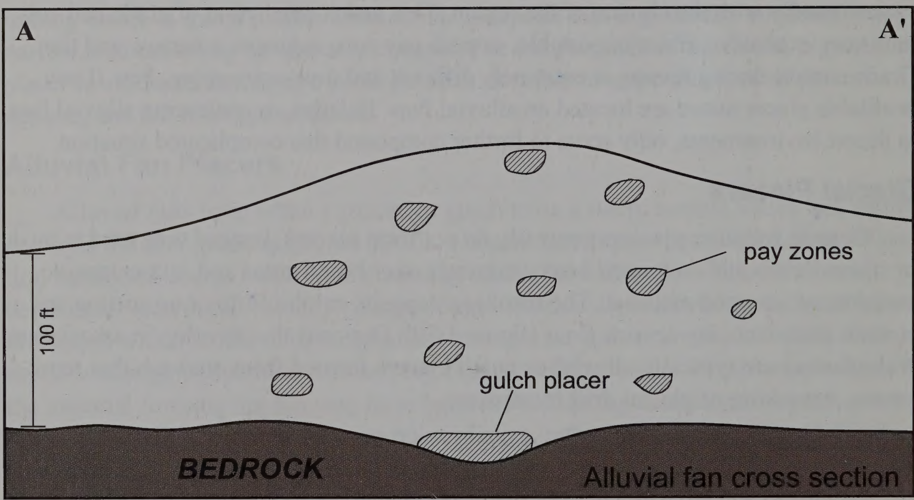




Figure 1.19. Generalized cross section and plan views of an alluvial fan placer.

## Transport Deposits

As their name implies, transport deposits (table 1.2) are distinguished from residual and lag deposits by the much greater distances that the constituent materials have been moved. This distance is commonly so great that there is no immediately apparent tie between the lode source and the placer deposits.

The effects of water transport are pronounced in these deposits, as they tend to be well-sorted and relatively fine-grained, and the clastic particles show rounding due to

Figure 1.20. Glacial outwash, Ferry area, Alaska. Note the mixing of many particle sizes and limited sorting.

abrasion. These particles are transported to a distant location in a hyperconcentrated stream flow and are ultimately deposited according to turbulence of the flow, water velocity, particle shape, and settling rates of the particles (Pierson and Costa, 1987).

Transport deposits are typically sedimentary deposits that, through repeated sedimentation and erosion, have resulted in concentrations of heavy minerals. Deposit values are more uniform at lower grade values, and locations of pay streaks are more predictable than those in lag deposits. The pay zones are often thousands of feet wide. The gold particles are typically small and flat. If the transport distances are great, folding and rolling of each particle is common. Understanding the mechanics of how these deposits form is key to comprehending their unique characteristics.

## Alluvial Deposits (Low-Gradient Rivers and Streams)

Alluvial deposits represent the largest volume and lowest grade of all of the types of placer deposits. These deposits are the largest in individual size and in historical production. The majority of historical research has established a consensus that placers result from the differential deposition of precious metals and lighter waste particles under normal bedload transport. In actuality, alluvial stream placers appear to be the product of endless sorting and resorting of the finer waste from the gold particles after the gold-bearing material is moved from the lode source.

Initially, the deposit is formed when the lode is eroded and the fine fraction is transported by hyperconcentrated stream flow. This stream flow contains enough clay and silt to restrict the settling of gravel and precious metal particles and allow prolonged suspension of the particles to a distant site. Clay particles tend to be attracted to each other as flocculates. The gravel particles, gold, and flocculates loosely bond, forming a substance that has a density lighter than the gravel or precious metal parti-

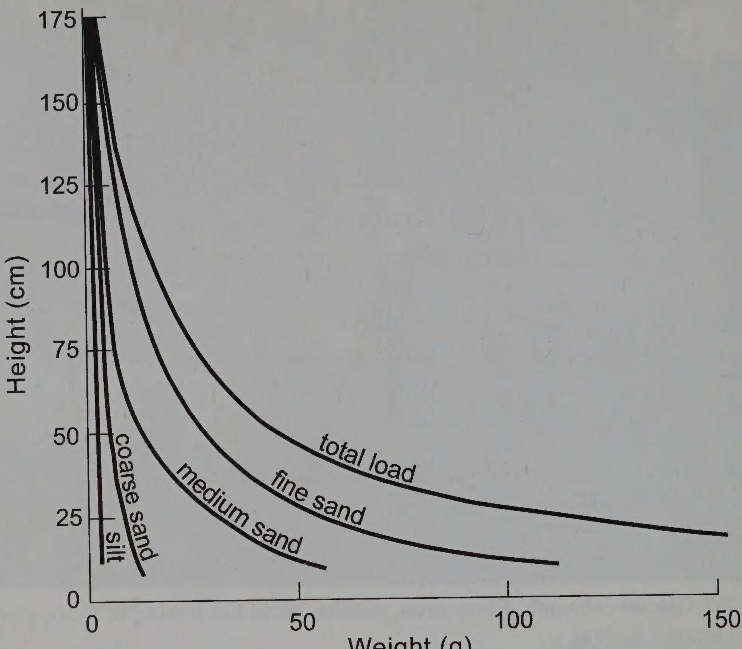


Figure 1.21. Percentage of different sediment sizes that were moved by wind at various heights above the ground in the Coachella Valley, California, during a 146-day period in July–December, 1953. The bedload was concentrated mainly below 1 m height (Skinner and Porter, 1987). Note: This location, Garnet Hill, near Palm Springs, California, is one of the most consistently windy and sandy places in North America. High-wind events in the area have caused the toppling of loaded railcars a few miles away. The location where the data in figure 1.21 were obtained is a type location for venifacts, or rocks that have been sculpted by windblown sand. A glass bottle wedged into a carefully chosen location at this site will become sandblasted in a few months. Garnet Hill is at the northwestern tip of the Salton trough, which culminates in the extensive Algodones Dunes complex in southeastern California and Baja California Norte, Mexico. Data portrayed in figure 1.21 will have limited application elsewhere.

cles (Pierson and Costa, 1987). Consequently, under the velocities in the hyperconcentrated stream flow, the particles can remain in suspension for a considerable distance before settling.

In time, water velocities may decrease for extended periods to levels that will not erode gold. During these periods, through normal bedload movement, only the barren gravel and an occasional tiny gold particle are moved (figure 1.22). This allows for enrichment through reworking and reconcentration. During this phase of reconcentration, smaller-size particles and flatter shapes tend to remain in suspension the longest and are carried by stream flow for the longest distances (figure 1.23). The sorting of heavy minerals corresponds to the overall particle size (larger gravels = more heavy minerals) and degree of sorting of the barren material.

Few historical reports mention climatic changes as an element of placer deposition. Extended periods of precipitation have a profound influence on the formation of the drainages and deposits (Molnar, 2001). Over time, these cyclic periods of climatic

Table 1.2 Characteristics of placer transport deposits

| Deposit type | Bedrock quality | Pay volume potential | Degree sorting | Volume clay and silt | Values | Grade consistency | Pay zone location | Waste particle size distribution | Waste particle degree roundness | Gold/crystal characteristics | Gold shape | Gold chemistry | Industrial mineral characteristics | Accessory minerals | Heavy mineral transport distance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream/ river/ alluvial | fractured and rough | medium to very large | medium to high | 10-20% | low to medium | lenticular, channelized or disseminated | bottom of channels or stratigraphic sequence; may be multi-zones | small to medium; sand to gravel; some cobbles | well-rounded to subrounded | abraded | medium and flat to small and equi-dimensional | silver-depleted rims; possible accretion; no inclusion | small to finely ground | few and fine; some magnetite | miles, but rarely hundreds of miles |
| Flood | fractured and rough | very small | high | none | medium to high | localized in micro-zones | first 2 ft depositional of surface | sand; silt and clay | flattened | no crystals | extremely flat and thin | silver depleted; no inclusions | none | none | miles to hundreds of miles |
| Beach | unim-portant | small to medium | high | none | low to medium | localized | in lenses | small; sand-sized | well-rounded | abraded | flat and thin | unknown | small; sand-sized | seen with magnetite, garnet, ilmenite and possibly chromite | hundreds of feet to miles |

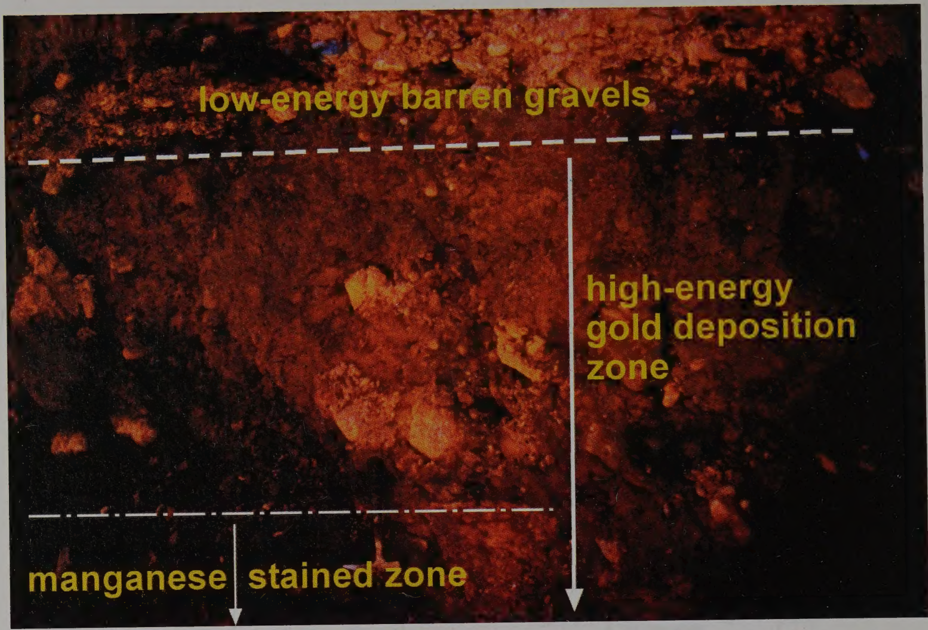


Figure 1.22. High-energy gold-bearing zone covered by low-energy barren gravels, McKormic Creek, Montana.

change may repeat and overprinting on the deposit may occur, resulting in multiple pay channels (figure 1.24).

Pay channels formed in this way may be shallow or hundreds of feet deep and well beyond the reach of conventional mining methods. The gravel is typically well-sorted but contains significant amounts of clay and silt (figure 1.25). The pay values are normally low but are consistent over hundreds of feet and represent large volumes. These deposits are the placer equivalent of low-grade, disseminated lode gold deposits.

## Flood Gold

Flood-gold particles have high ratios of surface area to weight and a Cailleux Flatness Index (= length x breadth/2x thickness) greater than 45 (Loen, 1995). They resemble tiny bits of the thin gold foil used to decorate greeting cards. The flakes travel with clay and silt-sized particles rather than in the gravel portion of the stream bed. In some places, such as the Snake and Salmon rivers of Idaho, the spring flood flow mobilizes these particles and transports them to the next depositional site. Similar conditions occur at the Hassayampa River in Arizona, which usually produces low-volume deposits.

The depositional site may be fractured, blocky bedrock, a point bar, a flood plain, or a midriver cobble skim bar (figure 1.26). All of these collect the seasonal enrichment of this fine gold in thin veneers of sand and silt, generally less than 2 ft thick. These zones can represent excellent hobby mining areas, but rarely contain sufficient gold-bearing yardage to justify mining equipment of any kind larger than a hand shovel.

## Beach Placers

Beach placers typically are derived from source areas near the coast that allow for short transport distance. Streams erode the source rocks and carry the heavy min-

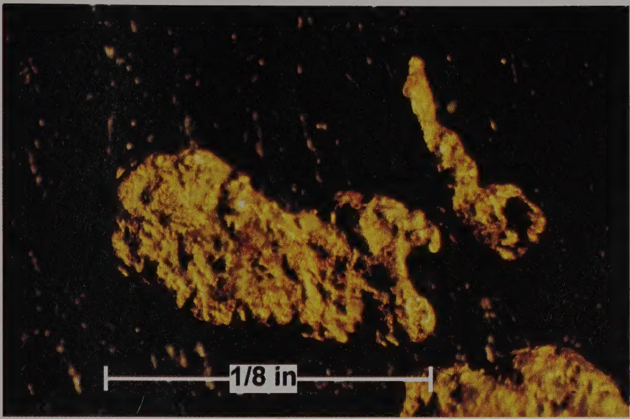



Figure 1.23a. Rough surfaces on gold with high weight to surface area ratios cause gold to settle out quickly in placer deposits. The rough surface has increased friction and enhanced settling rates.

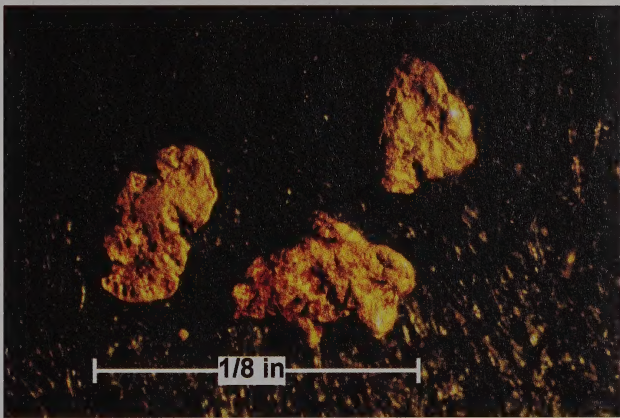



Figure 1.23b. Smooth surfaces on flat gold enable long-distance transport with silt and fine sand particles.

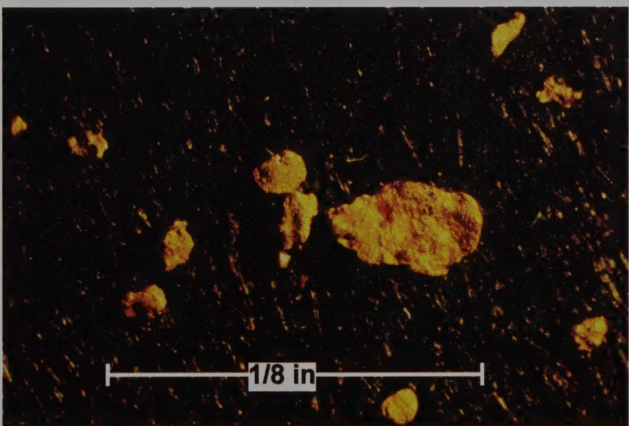



Figure 1.23c. Microfine gold with smooth surfaces and low weight to surface area ratios travels extensive distances in suspension and settles with fine silt and clay particles.

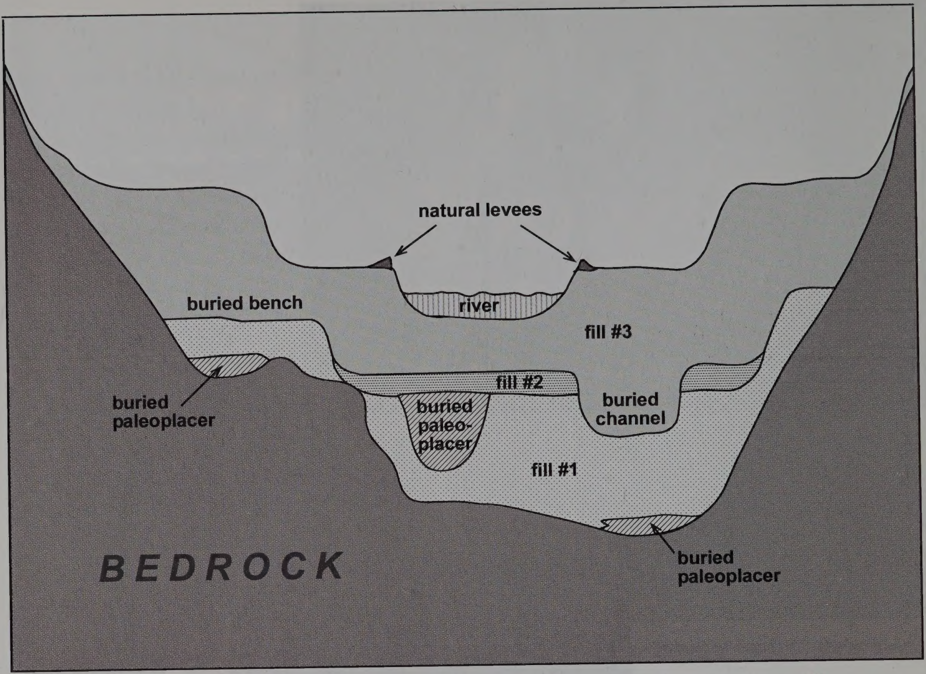



Figure 1.24. Terraces and buried channels in a river system showing three fill episodes.

Figure 1.25. A low-energy transport-type deposit in Quartz Creek, Mineral County, Montana.

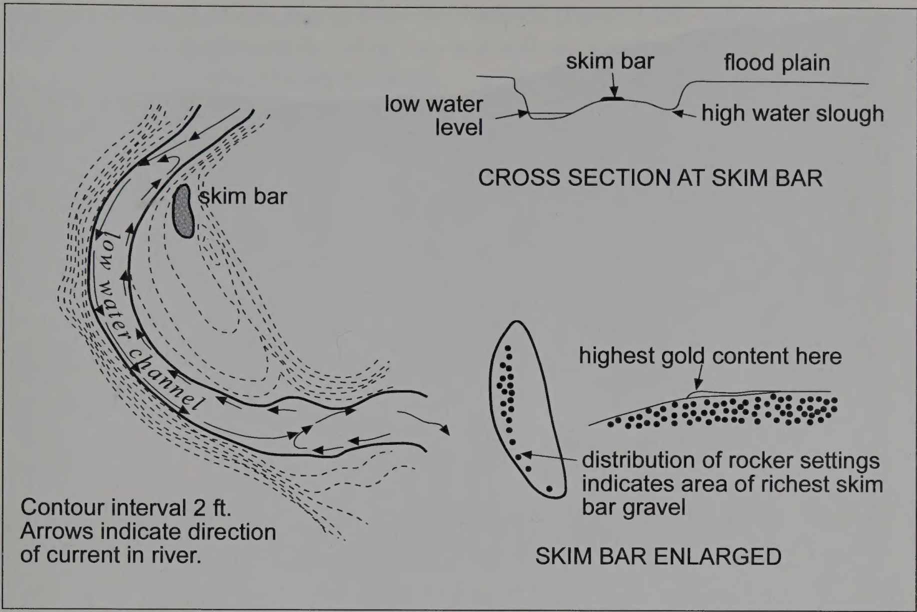



Figure 1.26. Sketch showing the location of flood gold on accretion, or skim bars. Relative flow velocities in the channel are proportional to the length of the arrows (Hill, 1915).

erals and gangue material to the ocean before deposition. Outcrops of lode deposits at or near the water line may be actively eroded by the power and velocity of the waves and contribute to the formation of beach placers; however, this is assumed to be a rare situation.

After reaching the ocean, velocities of the lateral and offshore currents, rip tides, and normal wave action sort the grains of sand by settling rates governed by particle size, weight, and shape (Komar and Wang, 1984). The lighter particles are moved along the shore while the heavier, denser particles move much shorter distances.

Beach deposits typically contain well-sorted lenses with concentrations of gold and other heavy minerals including magnetite, ilmenite, and possibly chromite (figure 1.27). The particle sizes range from silt to sand. Most gold (and possibly platinum) particles in these deposits are flat with folded edges and are of high purity. The accessory minerals are well-rounded.

Beach deposits are generally of low grade with localized enrichment zones. It is difficult to predict the locations of the pay streaks or channels due to the uniform sizes of the deposited material. Few, if any, beach precious metal placers have been successfully mined (Wells, 1969).

## Localized Depositional Controls

In addition to the mechanisms of concentration, bedrock characteristics are critical to deposition. A smooth bedrock surface dipping parallel to the stream gradient will not likely accumulate many heavy minerals. However, if the stream cuts across bedding or fractures, the riffles formed by the irregularities in the bedrock may collect

Figure 1.27. Platinum-bearing beach placer at Good News Bay, Alaska (Photo by Steve Fechner).


Figure 1.28. A rough-textured, angular bedrock surface collects more gold than smooth, unfractured bedrock surfaces (California Creek, Mineral County, Montana).

heavy minerals. A rough, highly fractured bedrock (figure 1.28) will serve to concentrate gold and heavy minerals, while clay and soft shale provide few of the irregularities that collect heavy minerals.

Resistant outcrops, dikes, or faults may act as local dams and form low-velocity deposition sumps that collect heavy minerals on the upstream side of the dam. Boulder concentrations or coarse lag gravels on bedrock may also form riffle-like features that concentrate heavy minerals during periods of deposition. Valley constrictions formed by erosion-resistant rock, landslides, or even tributary streams joining the valley may cause the formation of shallow pools immediately upstream from the constriction. These low-velocity zones allow heavy minerals to settle out in the upper end of the pool, while the area of constriction is scoured clean with the high-velocity water.

It is critical that the examiner gather all possible data of this kind to help explain inevitable sample value inconsistencies. Special effort must be made to identify the boundaries between localized enrichment and barren zones. During the sampling process, these areas must be sampled separately to determine the correct size and area of influence.

Evidence exists to support theories of direct precipitation of gold in the weathering environment, including bacterially induced precipitation of gold from solution (Southham and Beveridge, 1994). Other papers explore this potential of placer gold deposition in laterite weathering profiles (Mann, 1984; Evans, 1981). In these situations, the gold is leached out of weathered laterites by meteoric waters and redeposited on gold particles in the gravel. As early as 1910, it was recognized that some placers appeared to regain values with time (Freise, 1910).

Although laboratory simulations demonstrate the plausibility of the theory, the existence of chemical enrichment has little bearing on placer evaluation, and physically testing the property is the only way to determine the current value of a placer deposit.

# Interpretive Analysis of a Placer System

To properly evaluate a single placer deposit, it is critical that evaluators understand how each deposit relates to the entire placer system. After an identification of the deposit type has been made, it is much easier to understand the depositional and environmental factors such as lode source, stream size, energy levels, bedrock gradient, localized enrichment factors, and bedrock types that influenced or controlled the development of each deposit. By understanding these factors, the evaluator can reconstruct how the deposit was formed and what types of placers can be anticipated to exist within the system.

Every system is made up of several placer deposit types. How many types exist is controlled by the depositional environment, the number of depositional events, and the potential for overprinting of depositional or destructive events.

The area of Quartz Creek in Mineral County, Montana (plate 1), is an informative model. The following interpretation, although speculative in part, serves to illustrate the complexities of placer formation in a high-relief environment. The source area, as indicated by soil samples and geologic mapping, contains numerous mineralized northwest-trending extensional fault zones. Gold-bearing colluvial deposits are found down-gradient of these zones. The fault zones are also cut by many tributary streams. This forms a potential for many gulch deposits within the system, which would feed

the larger gulch deposits downstream. Residual placers exist to some extent directly above the fault zones.

The gravels in the lower portion of the 46 Gulch drainage appear to be the result of a debris-flow placer. A valley constriction in the Quartz Creek drainage below the mouth of St. Patrick Creek created a trap for the debris-flow deposit originating from the 46 Gulch. That deposit was subsequently covered with barren material from the upper Quartz Creek drainage.

Downstream on St. Patrick Creek, there is evidence of a high-energy flood event that deposited gold-bearing material in a gulch placer. Because of the energy of the event, gravel was deposited on the hillside at impact points up to 100 ft above the present base of Quartz Creek. The pattern of deposits indicates a decreasing frequency of impacts as the flow progressed downstream until it was near parallel to the valley walls. This event overprinted another gulch placer that pre-dated the flood event. Subsequent annual flood events reworked some of this deposit into the pre-existing gulch placer and then covered the entire deposit with overburden (figure 1.29).

At Tucker Gulch, the upper end of the drainage cut across a lode deposit and redeposited the gold as a gulch placer in the creek. At the mouth of the gulch the placer was subsequently eroded out, and the scoured zone filled with nearly barren gravel.

At an elevation of approximately 3,800 ft, the main creek appears to have entered the pool of Pleistocene Glacial Lake Missoula. As water velocity dropped, an alluvial deposit formed over the top of the pre-existing gulch placer. When Glacial Lake Missoula drained, the alluvial placer was reworked into the gulch placer, with the exception of the remnant benches from the valley fill.

At the mouth of Quartz Creek, the gulch placer took the form of an alluvial fan that may have dammed the Clark Fork River. That deposit was dissected by the river.

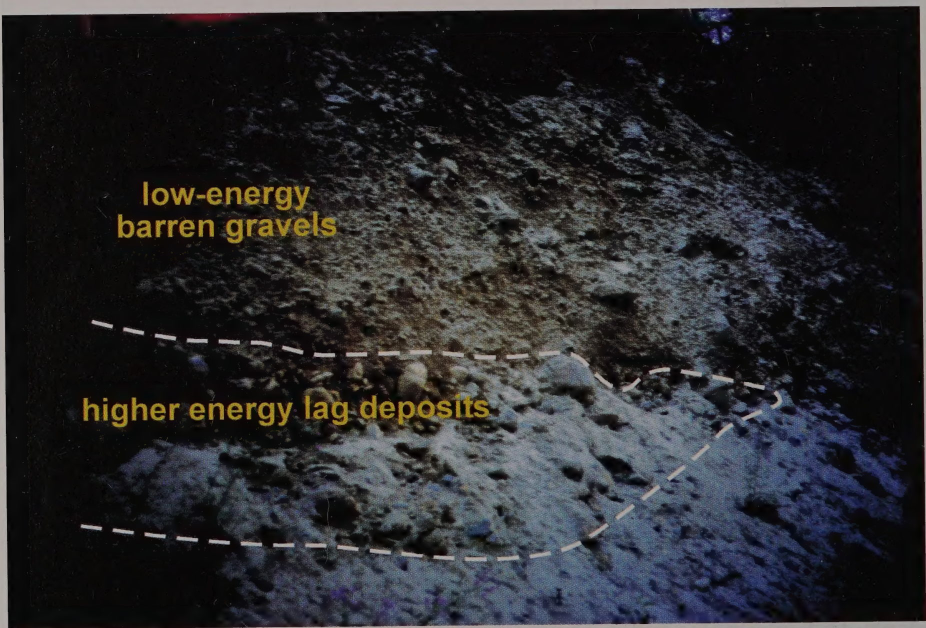



Figure 1.29. Low-energy barren gravels often cover the higher energy gold-bearing lag deposits (Quartz Creek, Mineral County, Montana).

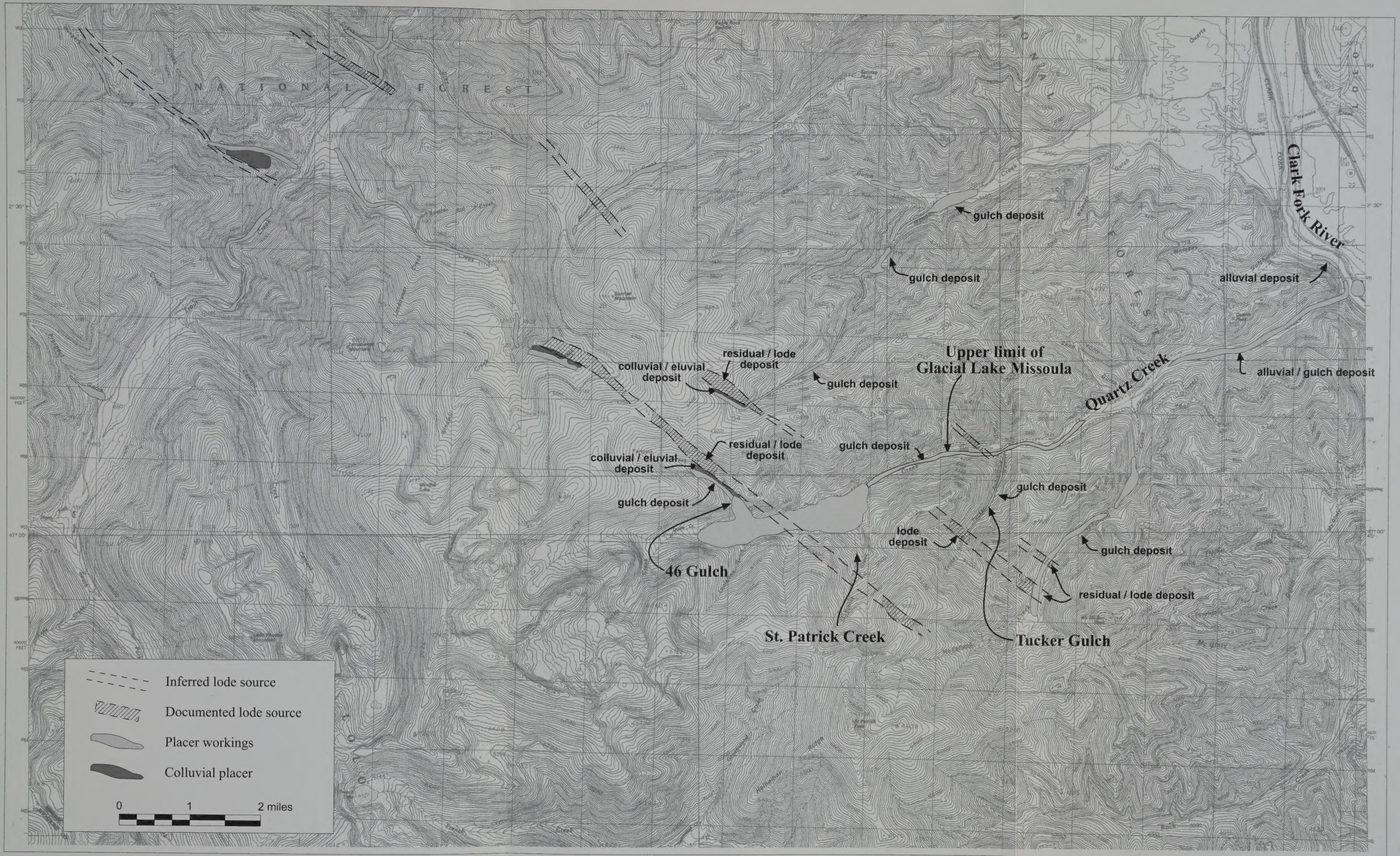



Plate 1. Quartz Creek placer deposit system.

The remainder of the original deposit presently exists 300 ft above the north side of the Clark Fork River. Below the mouth of the gulch, the Clark Fork formed alluvial deposits in the canyon. After the primary formation of the placers in middle Quartz Creek, 20 to 30 ft of barren gravel was deposited over the top of the placer deposits. Early miners covered these barren gravels with 10 ft of waste from ground sluicing and booming, further burying the unworked ground.

This example demonstrates the complexity of placer deposit formation. Multiple sources and deposit types (lode and placer), diversity of depositional environments, overprinting, reworking, and burial are the norm in placer formation, not the exception. If the examiner is patient and observant, a few exposures across the deposit will provide the necessary understanding of the placer deposit and possibly even the lode systems of the area. Evaluators with a better understanding of the formative factors of the deposit or deposits may produce a more accurate evaluation when determining mining cost estimates, property evaluations, and reserve estimates.

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# Chapter II: Lode Deposits and Sources of Placers

# Lode Sources

## Introduction

Placer deposits consist of not only valuable heavy minerals but also numerous associated lighter minerals that are indicative of the lode source, which in turn may reveal clues about the resource size, grade, fineness potential (gold purity), and predominant gold particle size. These accessory minerals may also affect the recovery of the primary minerals. For example, high percentages of heavy minerals such as garnet, magnetite, and ilmenite make gold recovery expensive and difficult. Although they have a lower specific gravity than gold, these minerals are heavy and abundant enough to "pack" riffles or other recovery systems and interfere with the recovery of gold.

The depth to which the source lode deposit has been eroded may dictate the products seen in the placer. For example, a porphyry–copper system may have contained sizeable amounts of gold near its top, but if it has been eroded deeply, placer deposits that formed downstream during earlier stages of erosion may be gone. The concentration and assemblage of the minerals change as distance from the source increases. Accessory minerals, as well as gold, are sorted by size, specific gravity, and shape. Therefore, the mineral assemblage of a placer adjacent to the lode may be significantly different from that of placers farther downstream. The gangue or non-mineralized fraction of the placer is also an important indicator of lode source. As samples are processed, the relative amounts of different rock and mineral types and subtle changes in gold characteristics such as color, shape, and texture should be observed and recorded, as should changes in types of accessory minerals (Loen, 1995). Together, these observations may help identify multiple sources or lode targets.

The potential size and grade of placers are dictated by the lode source. Small quartz vein deposits that are unfractured, unaltered, and unweathered most likely will not develop into quality placer deposits, because the gold will be encased by quartz. Mineralization in skarn deposits is typically spotty and difficult to predict, but can create large, rich placers with coarse nuggets (Loen, 1997).

## Deposit Types

Lode sources for placer deposits may be indicated by the fineness, or purity (parts per thousand), of the gold. A consistent relationship appears when fineness data from suspected and known lode sources are compared to data from historical placers. Available data for Montana placer deposits (table 2.1 and figure 2.1) show that placers derived from skarns range from 880 to 950 fine (880 to 950 parts per thousand pure gold). This group may be further divided, with lower fineness values being derived from carbonate-poor environments and higher values from carbonate-rich environments. The U.S. Bureau of Mines production records show a fineness range of 900 to 940 in skarns formed from relatively pure limestone such as at the Fish Creek deposit in Silver Bow County, Montana. Skarns formed in calcareous shales such as the Washington Gulch deposit (Finn District) have a fineness range of 877 to 932.

Low-sulfide quartz deposits, such as at Lincoln Gulch, Montana, yield placer gold with a fineness generally in the range of 800 to 880. The lower range of this group (800 to 820) seems to have some association with potassium feldspars in the veins, as seen at Alder Gulch, Montana.

Table 2.1. Gold fineness by deposit in Montana

| Drainage | County | Placer deposit type | Lode source deposit type(s)[1] | Gold fineness range[2] | Gold fineness average |
|---|---|---|---|---|---|
| Upper Emigrant | Park | Gulch | Porphyry–molybdenum, sulfide breccia pipes | 720–750 | 735 |
| Lower Emigrant | Park | Alluvial | Porphyry—molybdenum, sulfide breccia pipes | 820–851 | 836 |
| Bear Gulch | Park | Alluvial | Homestake gold | 884 | 884 |
| Gold Creek | Powell | Alluvial | Skarn gold, low-sulfide quartz | 861–900 | 882 |
| Snowshoe | Powell | Gulch | Skarn gold | 850–928 | 898 |
| Washington | Powell | Gulch, alluvial fan | Skarn gold, low-sulfide quartz | 877–932 | 896 |
| Wasson | Powell | Residual | Skarn gold, low-sulfide quartz | 842–853 | 848 |
| Jefferson | Powell | Gulch, alluvial fan | Skarn gold, low-sulfide quartz | 880–919 | 896 |
| Madison | Powell | Gulch | Low-sulfide quartz | 880 | 880 |
| Wilson | Powell | Residual | Skarn gold, low-sulfide quartz | 708–857 | 807 |
| German Gulch | Silver Bow | Gulch | Skarn gold | 824–983 | 905 |
| Silver Bow | Silver Bow | Gulch | Copper–porphyry | 352–770 | 640 |
| Fish Creek | Silver Bow | Gulch | Skarn gold | 920–985 | 967 |
| Skelley Gulch | Lewis & Clark | Gulch | Skarn gold | 900–910 | 905 |
| Lincoln Gulch | Lewis & Clark | Gulch | Low-sulfide quartz | 862–896 | 876 |
| Sauerkraute | Lewis & Clark | Gulch | Skarn gold? Low-sulfide quartz | 880–900 | 890 |
| Nelson Gulch | Lewis & Clark | Gulch | Skarn gold | 929–941 | 935 |
| Ten Mile | Lewis & Clark | Gulch | Copper–porphyry, polymetallic vein | 643–655 | 650 |
| Last Chance Gulch | Lewis & Clark | Gulch | Skarn gold | 827–907 | 889 |
| Browns Gulch | Madison | Gulch, possible residual | Unknown | 785 | 785 |
| Alder Gulch | Madison | Gulch | Low-sulfide quartz–potassium feldspar | 750–852 | 813 |
| Quartz | Mineral | Gulch | Metasedimentary shear zone-hosted gold? | 900–983 | 972 |
| Snowshoe | Mineral | Residual, colluvial | Metasedimentary shear zone-hosted gold? | 900–960 | 951 |
| Windfall | Mineral | Gulch | Metasedimentary shear zone-hosted gold? | 983–988 | 984 |
| Meadow | Mineral | Gulch | Metasedimentary shear zone-hosted gold? | 983–986 | 984 |
| Little Bear (Upper Meadow) | Mineral | Residual gulch | Metasedimentary shear zone-hosted gold? | 949 | 949 |
| Bannack | Beaverhead | Gulch | Skarn gold | 775–995 | 907 |
| Bonnecord (below Bannack) | Beaverhead | Alluvial (transport) | Skarn gold | 913–940 | 929 |
| Jeff Davis | Beaverhead | Alluvial, Gulch | Low-sulfide quartz ? | 815–906 | 874 |
| Indian Creek | Broadwater | Gulch, Alluvial fan | Skarn gold | 870–920 | 903 |
| Bear Gulch | Granite | Gulch | Skarn gold | 848–953 | 906 |
| Deep | Granite | Gulch, Colluvial | Skarn gold | 914–924 | 918 |
| Basin Gulch | Granite | Gulch | Veins, breccia pipes, diatremes | 730–900 | 734 |
| Prickley Pear | Jefferson | Alluvial (transport) | Polymetallic vein, copper–porphyry? | 705–805 | 738 |
| Basin Creek | Jefferson | Gulch | Copper–porphyry?, polymetallic | 637–642 | 640 |
| Kit Carson | Jefferson | Gulch | Polymetallic vein, porphyry-related | 612–630 | 621 |
| Elkhorn | Jefferson | Alluvial fan | Skarn, breccia pipes | 880 | 880 |

[1]Details for each type are provided in this chapter.
[2]Fineness equals parts per thousand pure gold; e.g., 900 fineness = 900/1000 pure gold.

Fineness below 780 appears to relate to porphyry or porphyry-related polymetallic vein systems, as shown in the areas of Butte and Silver Bow, Montana. This lower fineness is reflected in high silver-to-gold ratios and the highest rim enrichment on gold particles from leaching. Silver occurs within gold as blebs of elemental silver. If the silver is exposed on the gold surface, it may be leached out of the gold. In silver-rich placer gold, the silver blebs become interconnected and are leached more effi-

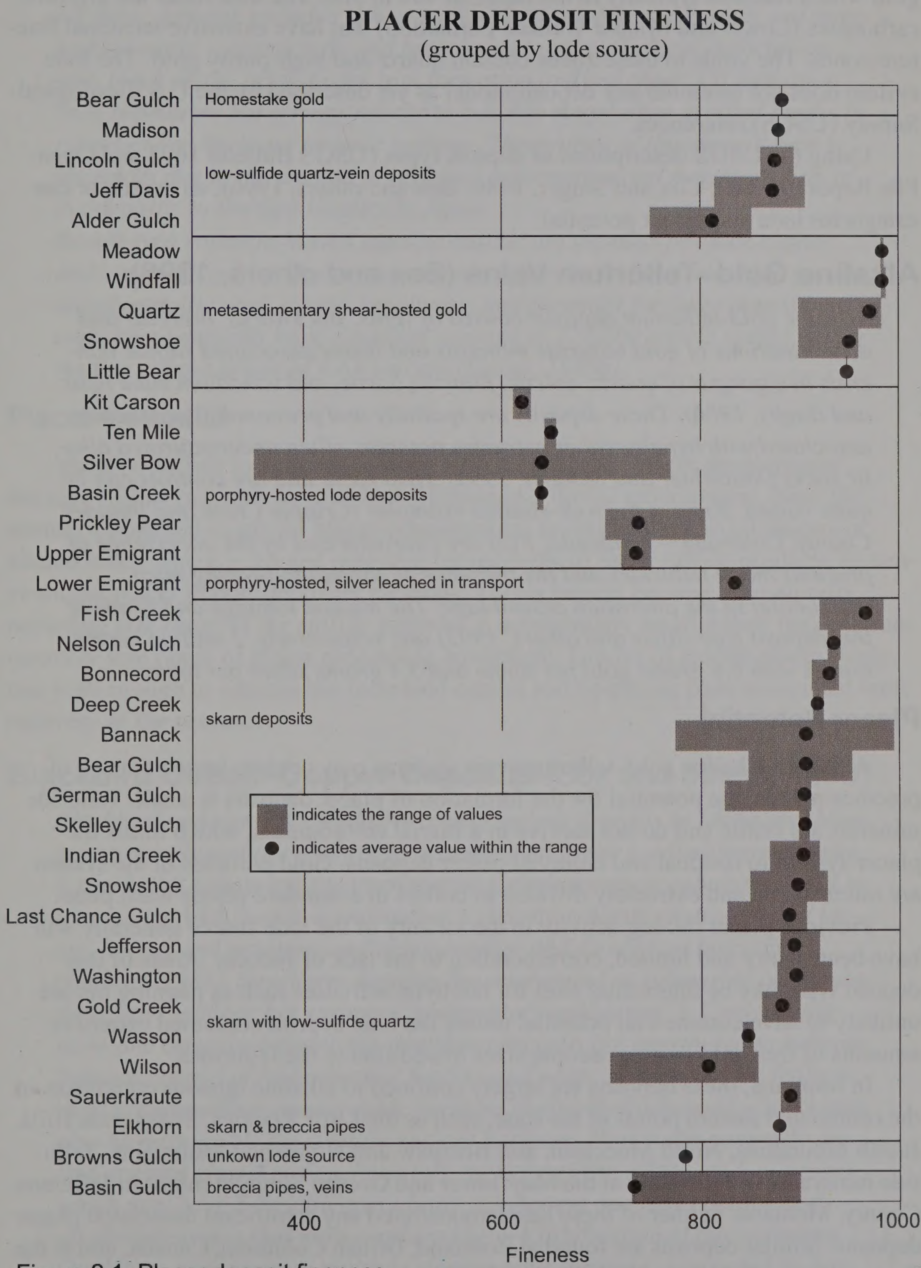


Figure 2.1. Placer deposit fineness.

ciently. This creates high-purity rims on the placer gold in much the same way that silver inquartation in fire assaying allows a better separation by gravimetric techniques. In assaying, the silver-to-gold ratio must range between 4:1 and 10:1 in order to get effective leaching (Shephard and Dietrich, 1940). Those ratios are approached in natural systems only in porphyry-sourced gold placers.

In northwestern Montana, near Superior, a unique district (Cedar Creek) contains gold with a fineness typically in the range of 960 to 980. The host rocks are argillitic carbonates (Lower and Middle Wallace Formation) that have extensive tensional fracture zones. The voids in these zones contain quartz and high-purity gold. The lode system does not resemble any deposit model as yet described by the U.S. Geological Survey (USGS) references.

Using the USGS descriptions of deposit types (USGS Bulletin 1693 and Open-File Report 95-682; Cox and Singer, 1986; Box and others, 1996), an evaluator can categorize lode and placer potential.

## **Alkaline Gold–Tellurium Veins** (Box and others, 1996)

*Alkaline gold-tellurium deposits consist of veins, stockworks, breccias and disseminations of gold telluride minerals and lesser associated sulfide minerals in a gangue of quartz, calcite, fluorite, barite, and vanadium mica (Cox and Bagby, 1986). These deposits are spatially and presumably genetically associated with hypabyssal or extrusive potassic, silica undersaturated alkalic rocks (Mutschler and Mooney, 1995). Host rocks and ore controls can be quite varied. Some of the well-studied examples (Cripple Creek and Boulder County, Colorado – Vatukoula, Fiji) are characterized by the occurrence of precious metal tellurides and the presence of vanadium-bearing mica (roscoelite) in the alteration assemblage. The median tonnage and grade of this deposit type (Bliss and others, 1992) are, respectively, 2 million metric tonnes with 6.6 grams gold per tonne and 3.4 grams silver per tonne.*

### Placer Potential

Although alkaline gold–tellurium vein systems may contain large volumes of precious metals, the potential for the formation of placer deposits is small. Telluride minerals are brittle and do not survive in a fluvial environment, which limits the placer system to residual and colluvial placer deposits. Gold particles in the system are microscopic and extremely difficult to collect in a standard placer wash plant.

Previous placer mining activity in the vicinity of the lode source generally will have been spotty and limited, corresponding to the lack of success. Areas of this deposit type may be interesting sites for hobbyist activities such as panning but are unlikely to have commercial potential unless the lode deposit contained extensive amounts of free gold in macroscopic sizes in addition to the tellurides.

In Montana, these deposits are largely confined to alkaline igneous complexes in the central and eastern points of the state, such as the Little Rockies, Sweetgrass Hills, Judith Mountains, North Moccasin, and Bearpaw and Highwood Mountains. Telluride minerals are also found at the Mayflower and Golden Sunlight mines in Jefferson County, Montana; neither of these has demonstrated any significant associated placer deposits. Similar deposits are found at Rossland, British Columbia, Canada, and at the Comstock and Gold Dike deposits in the Shasket Creek district of Washington state.

## Massive-Sulfide, Besshi-Type Deposits
(Box and others, 1996)

*Besshi massive-sulfide deposits are thin, sheetlike bodies of massive to well-laminated pyrite, pyrrhotite, and chalcopyrite within marine clastic sediments and mafic tuffs associated with submarine mafic volcanic and subvolcanic rocks (Fox, 1984; Cox, 1986a). The general exploration criteria for these deposits include (1) host rocks–clastic sedimentary rocks and interbedded mafic volcanic tuffs and breccia host rocks; (2) local association with black shale, oxide-facies iron formation and red chert; (3) formation from submarine hot springs related to basaltic magmatism in rifted basins in island-arc or back-arc tectonic settings. The genesis of this deposit type is uncertain due to the amount of regional deformation and metamorphism of the deposits in the type locality in Japan.*

*Besshi-type volcanic-hosted massive-sulfide ore deposits produce copper and zinc, with gold and silver as common byproducts. Relatively high grades of polymetallic ores, simple metallurgy, and potential for large deposits make these deposits have a median tonnage of 220,000 metric tonnes with a median copper grade of 0.64 percent (Singer, 1986b).*

### Placer Potential

Massive-sulfide lode deposits yield little potential for placer development because sulfide minerals have a short lifespan in a fluvial environment. Near the source, a potential exists for placer concentration as residual, colluvial placers or altered lodes. There is limited potential for recovery of these sulfide products by conventional placer gravity-recovery methods. This is largely because the naturally occurring size range of the sulfide particles is substantially smaller than the optimum recovery size range of placer processing equipment. Grades of sulfide placer rarely rise high enough to warrant the increased capital and operating costs associated with recovery of the resource.

## **Blackbird Cobalt–Copper Deposits** (Box and others, 1996)

*Blackbird sedimentary exhalative copper-cobalt deposits in Idaho and Montana typically contain massive to disseminated pyrite ± cobaltiferous pyrite ± pyrrhotite ± magnetite ± arsenopyrite ± chalcopyrite ± cobaltite ± gold in association with quartz ± tourmaline ± siderite ± barite in stratabound layers, lenses, and stringers and in concordant and discordant breccias (Earhart, 1986). Stratiform deposits are interpreted as submarine accumulations from seafloor hot springs ("sedimentary-exhalative"). Crosscutting veins and breccias beneath the stratiform deposits are interpreted to indicate fracture control of hydrothermal feeders and vents. Some selective replacement of subseafloor stratigraphic horizons during hydrothermal activity may also be responsible for stratabound ore horizons. Host rocks generally are fine-grained clastic metasedimentary rocks (argillite, siltite, and quartzite), which may have a basaltic pyroclastic component and may contain mafic-alkalic intrusions that were emplaced before lithification of the sediments. Ore lenses may occur at multiple stratigraphic horizons, separated by bar-*

*ren metasedimentary rocks. They tend to be localized near basin-bounding fault zones that were active during sedimentation, as evidenced by growth faults, soft-sediment folds, dewatering structures, and(or) intraformational conglomerates (Modreski, 1985; Nash and Hahn, 1989; Nisbet and others, 1994; and Himes and Petersen, 1990). The median tonnage and grade of a deposit of this type...is 4.5 million metric tonnes of ore with 0.1 percent cobalt and 1.75 percent copper.*

### Placer Potential

The placer potential for this type of deposit is limited. The gold is typically microscopic when liberated from the sulfide host, and there is very little potential for economic recovery using placer techniques.

## Ultramafic-Hosted Chromite and Platinum Group Metals Deposits

### Bushveld Chromium Deposits (Box and others, 1996)

*Layered, ultramafic to mafic intrusions, such as the Stillwater Complex, Montana, are uncommon in the geologic record (and in the United States) but are economically important because they can host magmatic ore deposits containing economic concentrations of chromium, nickel, copper, titanium, platinum-group elements (PGE) and gold. Chromite deposits in stratiform layered complexes are tabular sheets of rock from a mafic to ultramafic silicate magma and can be concentrated into layers by magmatic processes. Chromite abundance in individual layers ranges from those where chromite is only slightly enriched relative to adjacent layers to those that consist entirely of chromite. Chromite seams range from less than 1 cm to a few meters in thickness and are laterally persistent, commonly extending the strike-length of the layered intrusion. Chromite seams commonly are found in sequences of cyclically layered cumulates in the lower parts of the layered intrusions.*

*Stratiform chromite seams like those in the Bushveld chromium model can be enriched in PGE to the extent that they can be considered for development strictly on their PGE content alone. The UG2 chromite seam in the Bushveld Complex represents one of the major repositories of PGE in the world. The formation of a chromite seam may cause the exsolution of a small amount of immiscible sulfide liquid into which PGE will partition under favorable conditions. Base-metal sulfides and platinum-group minerals may occur as inclusions in or interstitially to chromite. Sulfide mineral abundances in chromites are generally low, much less than 0.1 volume percent.*

*Chromite seams are typically found by geologic mapping in layered igneous complexes. Barren and PGE-enriched chromite seams are macroscopically indistinguishable and geochemical analysis is required to establish if chromite seams are enriched in PGE.*

*Grade and tonnage distributions have not been constructed for these chromite deposits. Sizes of deposits depend on the thickness and lateral continuity of the chromite-enriched layers (which is ultimately limited by the*

*size of the host intrusion). Chromite ores also are classified by the composition of the ores ($Cr_2O_3$ content and Cr:Fe ratio). Grade and tonnage information for stratiform chromite deposits is summarized in DeYoung and others (1984), Stowe (1987), and Vermaak (1986). The largest resources are in the Bushveld complex where 100's of millions of tons of reserves and billions of tons of resources have been identified (Vermaak, 1986).*

## **Merensky Reef PGE Deposits** (Cox and Singer, 1986)

Stratiform, disseminated sulfide (reef-type) mineralization in layered, cumulate mafic-ultramafic plutons can be enriched in PGE and is a major source of PGE in the world (Page, 1986a). Sulfide mineral abundance in these deposits is low, typically in the range of 1 to 5 volume percent. The mineralized interval is thin (tens of centimeters to a few meters) relative to the thickness of the layers of rocks in the host intrusion (kilometers). Mineralized intervals are laterally persistent and typically extend the length of the layered intrusion (up to hundreds of kilometers). In most deposits and prospects, sulfide minerals are concentrated near an interval that marks a major lithologic and petrologic change in the cumulate stratigraphic section. Pegmatoidal textures are common in some deposits. The exsolution of immiscible sulfide liquid from a mafic silicate magma is the fundamental ore-forming process. The textures and mineralogy of sulfide ores record a prolonged and complex process of solid-state transformation and recrystallization starting after solidification of the sulfide liquid. For the Stillwater Complex, the sulfide mineralogy resulting from the solid-state recrystallization of high-temperature sulfide phases is dominated by pyrrhotite, pentlandite, and chalcopyrite. Most of the platinum resides in discrete platinum-group minerals whereas most of the palladium is in solid solution in pentlandite.

There are few examples of this type of mineralization. PGE is being mined from two PGE-enriched stratiform layers: the Merensky Reef in South Africa and the J-M Reef in Montana. Even though PGE exploration efforts worldwide in the late 1980s found several lower-grade and currently subeconomic deposits, there are still too few deposits to construct statistically robust grade and tonnage distributions.

## **Alaskan Platinum Group Elements** (Cox and Singer, 1986)

The Alaskan PGE can be summarized as cross-cutting ultramafic to felsic intrusive rocks with approximately concentric zoning of rock types containing chromite, platinum, titanium, vanadium, and magnetite. They are also referred to as zoned ultramafic chromite–platinum deposits and Kachkanar-type deposits (Cabri and Naldrett, 1984).

The associated rock types include dunite, wehrlite, harzburgite, pyroxenite, magnetite–hornblende pyroxenite, two-pyroxene gabbros, hornblende gabbro, hornblende clinopyroxenite, hornblende–magnetite, clinopyroxenite, olivine gabbro, and norite. Post-orogenic tonalite and diorite are commonly spatially related. Orthopyroxene-bearing rocks are absent in deposits of this type in the Klamath Mountains in Oregon.

The age range of Alaskan PGE is Precambrian to late Mesozoic with most deposits being Paleozoic and Mesozoic. The rocks exhibit a variety of textures, including cumulus poikilitic, mush flow, lineated fabrics, and layered.

The deposits are typically found in unstable tectonic areas in layered ultramafic and mafic rocks that intrude into granodiorite, island arc, or ophiolite terranes. Evidence indicates shallow levels of emplacement.

The mineralogy consists of two different assemblages. The first consists of chromite ± platinum–iron alloys ± osmium–iridium alloys ± platinum–iridium ± pentlandite ± pyrrhotite ± native gold and/or PGE arsenide. The second consists of titanium–vanadium magnetite ± platinum–iron alloys ± osmium–iridium alloys ± cooperate ± bornite and/or ± chalcopyrite. The first assemblage will occur in clots, pods, schlieren, wisps of chromite in dunite, clinopyroxenite, and harzburgite. The second assemblage commonly occurs as magnetite segregation, layers in wehrlite, pyroxenite, and gabbro.

There is rarely any post-mineralization serpentinization or any other alteration present. The ore emplacement appears to be restricted to specific rock types by magmatic processes. Mechanical weathering produces PGE placers while chemical weathering could produce laterites as well.

The geochemical signature is typically chromite, PGE, titanium, vanadium, copper, nickel, sulfur, and arsenic. The second assemblage of ores in the Klamath Mountains is typically low in chromite and nickel. Examples of these deposits are Urals, USSR (Duparc and Tikonovitch, 1920); Duke Island, USAK (Irvine, 1974); Guseva-gora, USSR (Razin, 1976); Tin Cup Peak, USOR (Page and others, 1982), and Good News Bay, Alaska (personal communication, Alaska Geological Survey).

## Placer Potential

The placers formed from the previous three ultramafic-hosted deposit types contain large volumes of magnetite, ilmenite, chromite, and other related ultramafic-sourced heavy mineral assemblages. The potential for PGE and gold placers depends on how these metals occur. If the metals are contained within sulfide minerals, the individual particles will be small and unlikely to form an economic placer. If they form as free metals in association with the other minerals, there is a limited potential that an economic placer resource will form.

Because of the large volumes of heavy metallic oxides, precious metals in these concentrates are difficult to recover and separate. The bulk of the concentrates are usually composed of chromite and magnetite, which inhibit concentrations of the other metals. Even smelters have difficulty processing concentrates of these minerals.

Chromite/magnetite placers have been worked for gold and platinum near Gold Beach, Oregon; platinum-group metals have been dredged at Good News Bay, Alaska. Both operations met with limited success. In North America, most of the deposits of this type are beach placers derived from ultramafic parent sources. Although the volume potential is large, the overall grades are low to medium, with low recoverability at medium to high costs.

## Carlin-Type Sediment-Hosted Gold Deposits
(Box and others, 1996)

*Carlin-type sediment-hosted Gold deposits are bulk-minable gold deposits that are hosted mostly in sedimentary rocks that commonly contain pyrobitumen (a residue of thermally mature petroleum). Carlin-type deposits also commonly occur in association with felsic dikes and(or) hydrothermal jasperoids. Carlin-type gold ore is characterized by submicron-sized "invisible" gold, which occurs as discrete grains and is incorporated within fine-grained disseminated pyrite (Berger and Bagby, 1991; Christensen, 1993). Arsenian pyrite, realgar, orpiment, arsenopyrite, native arsenic, cinnabar,*

*stibnite, and base-metal sulfides and sulfosalts are characteristic ore minerals; and quartz, calcite, and barite are characteristic gangue minerals (Berger, 1986a; Hofstra and others, 1991). Characteristic alteration styles include decalcification, silicification, argillization, sulfidation, and introduction of the minerals barite and alunite (Christensen, 1993).*

*Silty dolomite and limestone (formed as carbonate turbidites in somewhat anoxic environments) are particularly favorable host rocks (Berger, 1986a), but siltstone, sandstone, conglomerate, and interbedded chert and shale may be mineralized also (Percival and others, 1988). Ore distribution is controlled by host rock permeability, which may result from primary lithology, fracturing, and(or) chemical alteration, such as decalcification (Christensen, 1993).*

*According to Christensen (1993), deposits of the Carlin district are of three structural styles: (1) stratabound replacement deposits within silty carbonate units (commonly overlain or overthrusted by relatively impermeable argillitic cap rocks); (2) deeper vein-like mineralized feeder structures; and (3) shallower stockworks of veinlets.*

*Genetic models for Carlin-type deposits are strongly contested by adherents to three schools of thought focused on (1) sedimentary associations, (2) magmatic associations, or (3) structural controls. These are reflected in the criteria emphasized by different estimation teams. The northwest team emphasized sedimentary associations, the Utah team emphasized magmatic associations, and the Nevada team emphasized structural thickening of the sedimentary section by thrust faulting.*

*As noted by Christensen (1993), a large-scale process, capable of establishing large convection cells, seems to be required in order to form long, linear groupings and widely scattered examples of similar deposits. Thorman and others (1995) and Alcaic and Barton (1995) suggest that mineralization accompanied the onset of widespread crustal extension and heating, accompanied by widespread volcanism in Nevada between 42 and 34 Ma (Thorman and others, 1995; Folder and others, 1995; Alcaic and Barton, 1995).*

*Since the discovery of the Carlin deposit in 1961, 30 separate centers of gold mineralization have been identified along the Carlin trend (Christensen, 1993), and 49 economically significant deposits have been discovered in a region that includes the eastern two-thirds of Nevada, western Utah, and southern Idaho. These large-tonnage deposits (median 6.6 million metric tonnes with median grade of 2.3 grams of gold per tonne: Mossier and others, 1992) have been the most important source of major new gold production in the United States in the last 30 years. Areas of exposed bedrock generally have been well explored, especially along the favorable trends. Therefore, current and future exploration efforts will be increasingly directed toward covered deposits and deep extensions of known deposits along the favorable trends.*

*The upper parts of Carlin-type Gold-Ag deposits are mined from open pits, and the gold is recovered from oxidized ore by heap leaching with dilute cyanide solutions. Zones of weathered and oxidized ore commonly extend to depths of several hundred feet. Oxidation of pyrite liberates gold and destroys pyrobitumen, which can interfere with recovery of gold from preg-*

*nant heap-leach solutions. Production from deep, unoxidized extensions of Carlin-type deposits will require underground mining, followed by oxidation of the ore in autoclaves (pressurized oxidation vessels), so that gold can be thoroughly extracted by cyanidation.*

### Placer Potential

The placer potential for this type of lode deposit is low. The gold is typically submicroscopic in size, with associated sulfides; neither characteristic lends itself to forming placer deposits. Residual and colluvial placer deposits derived from typical Carlin-type ore would not be responsive to standard recovery systems.

## Coeur d'Alene Silver–Lead–Zinc Veins
(Box and others, 1996)

*Coeur d'Alene (CDA)-type polymetallic veins are mesothermal replacement veins that are deposited from metamorphically derived hydrothermal fluids along faults within regional metamorphic shear zones in clastic low-grade metasedimentary terranes (Frykland, 1964; Beaudoin and Sangster, 1992). Silver, lead, and zinc are the most important products derived from CDA veins. Copper, gold, antimony, arsenic, and cadmium are byproducts. Cobalt, tungsten, uranium, and mercury also may be geochemically enriched.*

*Galena, sphalerite, and tetrahedrite are the main ore minerals and occur in various proportions. Typical gangue mineral assemblages include quartz ± siderite ± other carbonates ± barite. Gangue minerals were deposited early and continued to be deposited with the ore minerals. The typical sequence of ore-mineral deposition is early magnetite, pyrrhotite, uraninite, and arsenopyrite, followed by intermediate galena, sphalerite, and tetrahedrite, and late chalcopyrite (Guilbert and Park, 1985, p. 486). Some veins are mined mostly for lead and zinc, whereas others are mined mostly for silver, and a few, which contain pyrite and scheelite, are mined mostly for gold.*

*Fluid inclusion data indicate that ore deposition occurred at about 350° to 250°C, from hydrocarbon-bearing fluids that are interpreted as metamorphic-hydrothermal in origin (Leach and others, 1988). Replacement textures are common, with carbonate minerals and quartz replacing wall rocks, and ore minerals replacing earlier gangue and ore minerals. According to Lindgren (1933), "metasomatic action, indicated by the presence of siderite in the quartzite, often spreads for 100 feet or more beyond the ore." Disseminated ore minerals also are found in the wall rocks of some veins (White, 1989). Tonnage-grade models have not yet been made for Coeur d'Alene-type veins, but the median tonnage and grade for mines of the Coeur d'Alene district (calculated from the production and resource data of significant deposits in Table 6) is 1.85 million metric tonnes of ore with 179 grams silver per tonne, 4.55 percent lead. Zinc contents of veins generally range from 0 to 10 percent. These tonnage-grade data are for mines, not individual ore shoots or veins. Tonnage-grade data for analogous deposits in Europe are incomplete. More than one model will be required, because lead-zinc veins have different tonnage-grade characteristics, as do associated bodies of semi-massive to disseminated mineralization in the host rocks.*

## Placer Potential

Lode deposits of this type are base-metal sulfides with limited amounts of free milling gold. There does not appear to be any historical placer production or potential from CDA-type deposits.

## **Epithermal Vein, Comstock** (Box and others, 1996)

*Epithermal gold-silver veins consist of moderately to steeply dipping sheets of quartz with ribbonlike ore shoots of precious metal minerals deposited in through-going faults or fractures from hydrothermal waters within 300 meters of the ground surface. These epithermal veins are divided into two types: pyrite-rich quartz-alunite and pyrite-poor quartz-adularia types. Quartz-adularia veins have been subdivided into three subtypes, Comstock, Sado, and Creede, based on their metal grades and the presumed character of the basement underlying the volcanic sequence in which they are found (Mossier and others, 1986a). The Comstock subtype, rich in silver and low in base metals, is generally found in or near volcanic piles overlying low-grade metasedimentary basement rocks (Mossier and others, 1986c). Where the ground surface from the time of vein formation is preserved, these silica-rich vein systems typically branch upward into a more dispersed system of stock-work veinlets, culminating in siliceous sinter (silica deposited in hot-springs pools) at the paleoground surface. The cluster of volcanic centers called the Yellowstone caldera system in northwestern Wyoming is an excellent example of a modern geothermal system. The deeper parts of systems like this are the environment where epithermal vein deposits form. Ore shoots typically form in the zone of boiling in epithermal veins.*

*Epithermal vein systems are formed in and around volcanic eruptive centers and(or) buried igneous intrusions, which provide heat sources to drive the hydrothermal systems. Fracture and fault systems that were active during volcanism provide repeated openings for ascending hydrothermal waters, localizing repetitive deposition of epithermal vein minerals. Since epithermal veins typically form within the volcanic pile within 300–400 meters of the ground surface, the presence of preserved volcanic piles is usually (though not always) required for the preservation from erosion of associated epithermal veins. Permissive tracts for epithermal veins are typically drawn around volcanic piles that have survived post-volcanic erosion. In the western U.S., volcanic fields of Tertiary age (0–65 million years old) are the typical host for epithermal vein systems. These narrow, relatively high-grade gold-silver deposits (median tonnage = 770,000 metric tonnes with median gold grade of 7.5 gram per tonne and median silver grade of 110 grams per tonne; Mossier and others,1986d) are typically developed in underground mines.*

## Placer Potential

Epithermal systems are renowned for their characteristics of low-grade, finely disseminated gold. In both oxide and sulfide-hosted systems, the metallic particle is typically micron-sized. Localized high-grade veins may be associated with the deposit and could provide sources for small placers, but extensive medium- to high-grade placers are not commonly associated with this deposit type. A placer from this

source would be expected to have high levels of cinnabar and possibly native mercury in the concentrates.

Deposits such as McDonald Meadows near Lincoln, Montana, have not had enough erosion to expose the gold zone; thus no potential for a placer exists. Adjacent areas near Keep Cool Lakes, which have patented placers with no lode source identified, occur in a similar geologic environment. Consequently, the placers may indicate some lode exploration targets.

Many Nevada properties fit this model, and few have developed significant placer deposits. This may be symptomatic of the deposit type but may also be due to the dry climate. The only reported lode deposit of this kind with a notable placer was at Bodie, California. Colorado Creek in southwest Alaska may also have been derived from a lode deposit of this source type.

## Massive-Sulfide, Cyprus-Type Deposits
(Box and others, 1996)

*Cyprus massive-sulfide deposits are massive, stratabound copper-, zinc-, and iron-sulfide accumulations deposited with submarine basalt in ophiolite sequences (Singer, 1986a). Recent work in modern ocean basins has identified active modern analogues at hydrothermal vents associated with modern mid-ocean ridge and back-arc basin spreading centers (Koski and others, 1994). These deposits are formed in deep ocean basin environments and are emplaced into and onto continental crust in a variety of complex boundaries between oceanic and continental plates.*

*The deposits typically consist of two parts: an upper, stratiform body of massive sulfides (>60 percent sulfides) and a lower, crosscutting stockwork of sulfide veinlets with wall rock alteration (replacement of feldspars with secondary chlorite, epidote, calcite and quartz). Copper is typically the economic commodity, with subordinate values of zinc, lead, cobalt, gold and silver. The median size of a Cyprus massive-sulfide deposit is 1.6 million metric tonnes with a median grade of 1.7 percent copper (Singer and Mossier, 1986a).*

### Placer Potential

Deposits of this kind are primarily base-metal deposits in a sulfide matrix. Any free gold present is most likely quite small and not likely to form placer deposits of any significant proportions.

## Distal Disseminated Silver–Gold Deposits
(Box and others, 1996)

*Distal disseminated silver-gold deposits (Graybeal, 1981; Cox, 1992) are low-grade precious-metal deposits found in carbonate-rich sedimentary rocks distal to porphyry-copper deposits in the same districts as porphyry-related copper- and zinc-lead-skarn, polymetallic replacement deposits, and polymetallic veins. The model is similar to that of the Carlin-type, sediment-hosted gold deposits, but these deposits have significantly higher silver grades. Ore minerals (native gold, native silver, electrum, argentite, silver sulfosalts, tetrahedrite, minor lead, zinc, copper, and iron sulfides) are sparsely disseminated or in stockwork of thin quartz-sulfide veinlets. Depos-*

*its occur in a wide variety of favorable host rocks, commonly carbonate-bearing sedimentary rocks but including non-calcareous clastic sedimentary rocks. They are typically found in folded and faulted shallow- and deep-marine sedimentary rocks that are intruded by I-type granitic rocks. These large-tonnage deposits (median size — 7.4 million metric tonnes; median gold grade — 1.1 grams per tonne; median silver grade — 42 grams per tonne: Cox and Singer, 1992a) are typically developed in open-pit mines.*

### Placer Potential

Placer gold from this source characteristically contains high silver-to-gold ratios. Because of the association with porphyry-related copper skarns and polymetallic veins, a potential for large low-grade placers exists. Near-source placers may exhibit extensive amounts of sulfides in the concentrates and quartz attachments on the gold. Native silver, which is common in the lode, is unlikely to exist in the placer because of the solubility of silver in water. Low-gradient transport environments may provide substantial placers near the source with medium to large percentages of black sand.

## **Hot Spring Gold–Silver Deposits** (Box and others, 1996)

*Hot spring gold-silver deposits are surficial and(or) near-surface expressions of hydrothermal systems, driven by high heat flow associated with intermediate to felsic volcanic fields. Hot spring gold-silver deposits typically are localized in zones of extensional fractures or in dilational openings within transpressional fracture zones (Berger, 1986c). Host rocks include volcanic and subvolcanic intrusive rocks as well as adjacent country rocks with high permeability or hydrothermally altered rocks with high fracture permeability (Berger, 1985). Hot spring sinter is typically present at the paleosurface, and the disseminated or vein-type gold ore bodies occur below the sinter and are localized along through-going structures. The geothermal systems of Yellowstone National Park (where gold is known to occur in subeconomic grades) are considered to represent a modern analogue for this deposit type (White and others, 1992). Associated mineral deposits include hot spring mercury deposits and antimony deposits. Hot spring deposits generally focus downward into a vein system of the Comstock, Sado, or quartz alunite type, and the boundary between the two deposit types is rather arbitrarily placed. Typically, the hot spring deposits are much larger in tonnage and lower in grade than the underlying vein deposit. However, some epithermal deposits, mined by open-pit methods, are more appropriately placed in the hot spring category because of their reported tonnage and grade, even though evidence for a paleosurface is lacking. Hot springs gold-silver deposits are large-tonnage, low-grade deposits (median size —13 million metric tonnes; median gold grade = 1.6 grams per tonne; median silver grade = 2.9 grams per tonne; Berger and Singer, 1992).*

### Placer Potential

Hot springs deposits are the disseminated uppermost portion of an orebody that may give way to a Comstock, Sado, or quartz alunite vein system at greater depths. The gold particles derived are likely to be small and associated with cinnabar or

native mercury in the concentrates. Because of the small size of the metallic gold particles, it is unlikely that the area around the lode deposit will contain significantly large gold placers with sustainable economic values. A possible example of a placer derived from this deposit type is Bogus Creek in Southwest Alaska, near Nyac (personal communication, Alaska Geological Survey).

## **Homestake Gold Deposits** (Box and others, 1996)

*Homestake gold deposits are stratiform deposits interlayered with iron-rich chemical sediments (silicate- and carbonate-facies iron formation) in Precambrian metavolcanic and metasedimentary terranes (Berger, 1986b). Ores are typically bedded, even finely laminated, in iron-rich siliceous or carbonate-rich chemical sediments with underlying veins or stockworks in feeder zones to these sediments. Gold commonly is localized in and around low-sulfide gold-quartz veins, stringers, and pods that form during greenschist facies metamorphism of the stratiform ores. These deposits typically occur in Archean greenstone belts of regionally metamorphosed mafic and felsic metavolcanic rocks, komatiites, and volcaniclastic sediments interlayered with banded iron formation. Deposits are commonly intruded by felsic plutonic rocks. The median size of Homestake Gold deposits is 2.8 million metric tonnes with a gold grade of 7.2 grams per tonne and byproduct silver (Klein and Day, 1994).*

### Placer Potential

Deposits of this type contain coarse gold in quartz and fine gold in massive sulfides. The gold in the quartz ore is easily liberated by grinding. In places where sufficient erosion of the lode has occurred, the placers are significant in grade and size. Scheelite is common in many of the Homestake-type lode deposits and resulting placer deposits. The gold and tungsten particles in the placer deposits are small. Alteration minerals associated with Homestake-type lodes are soft and do not accumulate in the placers derived from them.

At the original Homestake deposit, placers exist in a narrow drainage for over 6 miles. Although not extensive, they continue to produce gold. The gold is typically small; nuggets are uncommon. Similar deposits are located downstream from the Mineral Hill Mine near Jardine, Montana.

## **Low-Sulfide Gold–Quartz Vein Deposits** (Box and others, 1996)

*Low-sulfide gold-quartz vein deposits consist of gold-bearing massive quartz veins that typically contain a small amount of arsenopyrite and other sulfide minerals (<5 percent). The veins are vertically and horizontally persistent and have typically been deformed into pinch-and-swell structures due to compressive deformation (Berger, 1986d). As compared to gold-bearing polymetallic veins, which may also be mined primarily for gold, low-sulfide gold-quartz veins have lower contents of silver and higher ratios of gold to silver. These veins occur in belts of regionally metamorphosed (low to moderate metamorphic grade), marine sedimentary, and volcanic rocks, which are penetratively deformed and cut by high-angle regional-scale faults. Sig-*

*nificant deposits of low-sulfide gold-quartz veins are typically localized along major, deep-seated, through-going structural features. The median size of these small, high-grade deposits is 30,000 metric tonnes with 16 grams gold per tonne (Bliss, 1986).*

## Placer Potential

This deposit type is likely the source of placer deposits of Northeastern Oregon, the Mother Lode of California, and some of the coarse-gold paleoplacers of the Snake River (Seven Devil's Mining District) in Idaho. The gold ranges from microscopic pieces to large specimens measured in pounds. The lode sources have abundant milky white quartz gangue. In the Mother Lode area of California, metavolcanics, greenstones, and igneous intrusions are common hosts to the lode deposits. The placer gold ranges from angular to flat, and the deposits contain localized enrichments of zircon. Magnetite and ilmenite occur locally, but not in high percentages. Excavation of these deposits indicates that initially high-energy gulch placers were pervasive, but the amount of energy within the depositional systems appears to have steadily declined over time, allowing low-energy transport deposits to cover the earlier gulch placers. Typically, the best economic values are confined to the bottom 10 to 12 ft of the placer deposits.

Placer samples collected on placer projects near Grass Valley, California, contained microscopic quartz crystals and zircons. Some zircons were fresh, but an equal number showed fractures and/or abrasion to the point of being opaque. These show longer distance transport than the fresh zircons, which indicates derivation from multiple sources.

# **Overlook-Type Gold Deposits** (Box and others, 1996)

*"Overlook-type gold deposits" refers to a deposit type presently known only in northeastern Washington. The origin of these deposits is controversial. The following incomplete description of this deposit type is based on characteristics of the several known examples.*

*Overlook-type gold deposits are associated with stratiform bodies of massive magnetite. Typically the magnetite bodies are in sharp contact with limestone on one side and in fault contact with siltite-argillite on the other side. The deposits contain two types of ore: massive and veinlet. The massive ore consists of silicified, gold-bearing magnetite ± pyrrhotite ± pyrite ± hematite. The veinlet ore consists of gold-bearing quartz-pyrite-chalcopyrite veinlets and disseminated sulfides, in silicified argillite-siltite (Tschauder, 1989; Carden and others, 1992, Derkey, 1993; Rasmussen, 1993; Carden, 1995). The massive and veinlet ores commonly are in fault contact, and much of the massive ore is brecciated. Contacts of massive ore with unmineralized limestone are sharp and cuspate, and the limestone appears unaltered. Quartz-veined argillite-siltite is silicified, sericitized, and bleached. Gold grade is about 5 grams gold per tonne in both ore types, and at Lame Foot, the gold resource is about evenly divided between the two ore types. In both types of ore, gold is closely associated with sulfides, quartz veinlets, and pervasively silicified host rocks (silicified massive ore, brecciated and silicified massive ore, and silicified argillite-siltite). The median*

*deposit size is 2.7 million metric tonnes with 4.8 grams gold per tonne.*

*The origin of these deposits is controversial. In one model, massive magnetite-pyrrhotite-pyrite deposits are interpreted as epigenetic replacement deposits, hosted in limestone; and quartz-sulfide veinlets are interpreted as hydrothermal fracture fillings, hosted in argillite-siltite (Tschauder, 1989). In other models, the massive magnetite-pyrrhotite-pyrite bodies are interpreted as sea-floor volcanogenic massive oxide-sulfide deposits, similar to Australian deposits described by Davidson (1992), and the quartz-sulfide veinlets are interpreted as epigenetic veinlets, superimposed during a later hydrothermal event (Rasmussen, 1993).*

### Placer Potential

Coarse gold is rare in this deposit type, and consequently the potential for forming placer deposits is limited.

## Polymetallic Gold–Silver, Vein and Disseminated
(Box and others, 1996)

*Polymetallic quartz veins containing gold and silver, as well as lesser values of base metals, are widely distributed within and around the Idaho batholith in Idaho and southwest Montana and throughout the Blue Mountains of northeastern Oregon. As compared to low-sulfide gold-quartz veins, these polymetallic veins contain a wider variety of ore minerals and(or) have higher contents of silver (Berger, 1986d; Bliss, 1994a, 1994b). Where these veins occur in clusters and(or) have disseminated ore minerals in their wall rocks, they can be considered as large-tonnage, low-grade deposits with a distinctly different grade/tonnage distribution than that for individual vein deposits. Many significant placer gold deposits of the region were derived from such veins and vein clusters.*

*Polymetallic quartz vein deposits in the Blue Mountains are "predominantly narrow, quartz-rich fissure veins, breccia fillings, and associated replacement bodies along faults and shear zones" in argillite and granodiorite (Brooks and Ramp, 1968, p. 51). Quartz, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, and arsenopyrite are common in these veins. Pyrargyrite, proustite, stephanite, stibnite, cinnabar, petzite, and hessite are sparse to rare. Vein textures indicate mineral deposition by replacement and open-space filling. Veins are most abundant near contacts of Jurassic-Cretaceous plutons. Mineral assemblages of some vein sets are zoned with respect to the margins of such plutons (Hewett, 1931). Free gold is more common in oxidized parts of the veins than in reduced parts (below the water table), where much of the gold is contained in other ore minerals. The median size of this deposit type in the Blue Mountains is 76,000 metric tonnes with 18 grams gold per tonne and 12 grams silver per tonne (Bliss, 1994a).*

*In and around the Idaho batholith, most polymetallic gold-silver veins occupy steeply dipping faults and fissures, and many of them are localized within or near roof pendants or inclusions of metasedimentary rocks in the Idaho batholith. These veins generally are quartz-rich and commonly contain less than 5 percent of a wide variety of fine-grained ore minerals.*

*Arsenopyrite, pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, and stibnite are common. Bournonite, proustite, argentite, and electrum are sparse. Heubnerite, scheelite, hessite, cinnabar, and zinc-mercury sulfides are rare, but are characteristic of some veins. These veins commonly show evidence of multiple episodes of fracturing and healing by multiple generations of quartz, with various assemblages of ore minerals (Kiilsgaard and Bennett, 1987; Gammons, 1988; Kiilsgaard and Bacon, in press). The composition of an individual vein depends on its particular history of fracturing and healing during multiple pulses of mineralization in hydrothermal systems that changed with time. Wall rocks of some veins are pervasively silicified and sericitized, and contain disseminated ore minerals. Wall rocks of other veins are relatively unaltered. Free gold is more common in weathered and oxidized parts of the veins than in reduced parts (below the water table), where much of the gold is contained in other ore minerals. The median size of this deposit type in Idaho is 14,000 metric tonnes with 13 grams gold per tonne and from 0 to 55 grams silver per tonne (Bliss, 1994b).*

*Disseminated polymetallic gold-silver deposits are like polymetallic veins of the gold-silver subset, but they are large-tonnage, low-grade deposits that can be mined in bulk for gold and silver. These deposits consist of multiple sets of veins, mineralized breccias, and stockwork of veinlets, in silicified and sericitized host rocks that contain disseminated ore minerals. They occur along broad fault zones that show evidence of repeated breakage, movement, and hydrothermal mineralization. Multiple generations of quartz, with different combinations of ore minerals, indicate complicated histories of recurrent fracturing and mineralization within long-lived hydrothermal systems that changed from mesothermal to epithermal over time (Cookro and others, 1988; Bartels and others, 1990; Kiilsgaard and Bacon, in press). The known deposits of this disseminated type are located in and around the Idaho batholith. No similar disseminated deposits are known around the Blue Mountain vein systems in northeastern Oregon (Roger Ashley, USGS, oral communication, 1995). For the Idaho disseminated deposits, the median tonnage is 6.1 million metric tonnes with 1.75 grams gold per tonne and from 0 to 14 grams silver per tonne.*

Similar deposits are seen in Alaska in the Kougarok area on the Seward Peninsula (Alaska Geological Survey, written communication, 2001).

## Placer Potential

Except for skarns, the polymetallic gold–silver vein deposit model represents the most significant source of placers in Montana. The erosional level of the original lode deposit strongly controls the potential for placers. Many lode properties of this type have considerable gold values in the first 100 to 300 ft below the top of the deposit. Below that, many transition into sulfide-hosted base-metal systems with precious metal credits. Fineness of the gold in the placers is commonly in the low to middle 800s. Typically gold particles occur in a broad range of sizes, and some placers contain large nuggets.

In near-source placers, it is common to find galena and pyrite in the black sand concentrates. The farther from the source the less likely it is that the sulfide minerals survive.

## **Polymetallic Replacement Deposits** (Box and others, 1996)

*Polymetallic replacement deposits are hydrothermal epigenetic deposits that consist of silver-, lead-, zinc-, and copper-bearing minerals in massive lenses, pipes, and veins. They are hosted in carbonate sedimentary rocks that are intruded by porphyritic calc-alkaline plutons (Morris, 1986). They are typically associated with, but distal from, porphyry-copper mineralization. Types of alteration include dolomitization and silicification. On a district scale, the deposits are commonly zoned from a copper-rich central area, through a wide lead-silver zone, outward to a manganese- and zinc-rich fringe. Polymetallic replacement ores, also referred to as "manto-type deposits," contain galena, sphalerite, tetrahedrite, and other silver sulfosalts. Mineral zoning is common with inner zones rich in chalcopyrite or enargite and outer zones containing only sphalerite and rhodochrosite. Jasperoid is frequently found near ore bodies. Median size of these deposits is 1.8 million metric tonnes with 5.2 percent Pb, 3.9 percent Zn, 0.094 percent copper, 150 grams silver per tonne, and 0.19 grams gold per tonne (Mossier and others, 1986b).*

### Placer Potential

This deposit type typically contains only small amounts of gold. Targets in Montana—such as Hecla, near Melrose in Silver Bow County, the Castle Mountain district near White Sulphur Springs in Meagher County, and Elkhorn, near Boulder in Jefferson County—historically have not hosted any significant placers.

## **Porphyry–Copper Deposits** (Box and others, 1996)

*Porphyry–copper deposits are large-tonnage, low-grade hydrothermal ore deposits associated with altered, intermediate- to felsic-porphyritic intrusions and surrounding country rocks (Cox, 1986c). Copper-sulfide minerals occur in stockwork veinlets (± quartz) and as disseminated grains. These minerals are deposited from hot, saline solutions derived from cooling magma bodies within a few kilometers of the surface. Associated mineral deposits include polymetallic veins, base- and precious-metal skarn, and(or) base-metal replacement deposits (Cox, 1986c). Where erosion has exposed these deposits to the surface or near-surface environment, they are commonly capped by leached zones, containing copper oxides over carbonates in weathered outcrops, or barren outcrops with fractures coated by hematitic limonite. Enriched zones of secondary chalcocite and other copper sulfides may form at the water table (or paleowater table) by replacement of primary pyrite and chalcopyrite (Cox, 1986c).*

*Porphyry-copper deposits are generally found in magmatic belts associated with convergent plate margins. These deposits are associated with plutonic rocks of a wide variety of igneous compositions, ranging from diorite to granite. However, gabbros and high-silica granites are seldom associated with porphyry-copper deposits. Compositionally appropriate granitic plutons of Mesozoic and Tertiary age are widely scattered throughout the interior Columbia Basin and adjacent areas.*

*Porphyry-copper deposits commonly have significant gold and(or) molybdenum as byproduct commodities. Cox and Singer (1992b) divided porphyry-copper deposits into three subtypes based on their gold and molybdenum contents. Porphyry-copper-gold deposits have ratios of gold (in ppm) to molybdenum (in wt. percent) of 30 or greater. Deposits with gold-molybdenum ratios (as above) between 3 and 30 are considered porphyry-copper-gold-molybdenum deposits. From the worldwide data set, median tonnages are largest for the porphyry-copper-molybdenum deposits (500 million tonnes) and smallest for the porphyry-copper-gold deposits (160 million tonnes), and are intermediate for the porphyry-copper-gold-molybdenum deposits (390 million tonnes).*

*As gold and molybdenum contents are reported for only a few of the porphyry-copper deposits in the Pacific Northwest, it is not possible to classify the known deposits into the three subtypes. Instead, two regional grade-tonnage models were used to characterize these deposits: a North American subset of the general porphyry-copper model (Hammarstrom and others, 1993), used for areas underlain by Precambrian continental crust (e.g., Montana, Idaho, Wyoming), and a subset of the North American subset for significantly smaller deposits of British Columbia and Alaska (Menzie and Singer, 1993), used for areas underlain by Phanerozoic accreted terranes (e.g., Oregon, and Western Washington). The median size of a deposit from the North American porphyry-copper model is 142 million metric tonnes with 0.5 percent copper and byproduct values of silver, gold and molybdenum (Hammarstrom and others, 1993). The median size of a deposit from the British Columbia-Alaska porphyry-copper model is 86 million metric tonnes with 0.37 percent copper (Menzie and Singer, 1993).*

## Placer Potential

These lode deposits do not always develop significant placers. If they do, the gold has low to medium fineness. The lode sources in most of these systems are from either distal quartz veining or possibly gold skarns, depending on the host rock. The free gold is typically sourced from the uppermost 200 to 400 ft of the lode deposit.

Many of these systems contain tungsten and tin in minor amounts. Many near-source placers contain high concentrations of sulfides. Some gold may exhibit lacy edges or casts of sulfide crystals, if it is derived from sulfides. Most of the placer gold occurs in fine flakes, but small "match-head" nuggets are not unusual.

Placers in Butte, Montana, extend 7 to 10 miles downstream from the source. The gold is fine and flaky, with fineness ranging from 352 to 760; the average is about 650. The concentrates contain abundant pyrite, as does the stream bedload. Magnetite levels are fairly high but are derived from the intrusive host rock rather than being a product of ore mineralization. The Heddleston district, east of Lincoln, Montana, is a similar copper–porphyry deposit but has no notable placer signature.

## **Porphyry–Molybdenum Deposits** (Box and others, 1996)

*Two types of bulk-minable porphyry-molybdenum deposits are present in the Interior Columbia Basin: (1) low fluorine-type (Mo > Cu) and (2) climax-type (Mo only) deposits (Carten and others, in press). Significant molybde-*

*num resources are also present in porphyry-copper-molybdenum deposits discussed in the section on porphyry-copper deposits. The estimates of undiscovered deposits made here only apply to the low-fluorine type porphyry-molybdenum deposits.*

*For the low-fluorine porphyry-molybdenum model, median tonnage is 94 million metric tonnes of ore with 0.085 percent molybdenum (Menzie and Theodore, 1986).*

### Placer Potential

The majority of the deposits included in this model have not formed significant placers. Bald Butte, located northwest of Helena, Montana, had significant lode gold production in its early production years and is located in a gold district. However, base metals predominate in the lower part of the lode deposit. The depth of the gold production was shallow (<300 ft), much like that in the polymetallic vein model. The district exhibits some placer mining activity, but no extensive workings exist.

## Sediment-Hosted Copper, Revett-Type Deposits
(Box and others, 1996)

*Revett-type copper deposits are one of three subtypes of sediment-hosted copper deposits that are distinguished based on geologic setting, tonnage, and grade (Dennis Cox, written communication, 1994). Revett-type copper deposits occur in quartzite beds of the Revett Formation of the middle Proterozoic Belt Supergroup in western Montana and adjacent areas (Harrison, 1972). The deposits consist of elongate, stratiform bodies in which argentiferous copper sulfides and native silver occur as intergranular cements and as irregular replacement of clasts (Hayes and Einaudi, 1986). The sulfide and gangue components vary in mineralogy across a typical deposit, forming mappable zones of particular sulfide and gangue association (i.e., pyrite-calcite, chalcopyrite-ankerite, hematite, etc.). The median size of a Revett-type sediment-hosted copper deposit is 19 million tonnes with 0.86 percent copper and 40 grams per tonne silver (Spanski, 1992).*

*The sediment-hosted copper deposits form from a redox reaction between an oxidized brine (containing dissolved copper) and a reductant. The brine, in equilibrium with hematite and free of sulfide, maintains the copper in solution as a stable complex ion. The source of the brines may be trapped seawater or fluids derived from evaporate basins. The copper in the brines may be derived from volcanic rock clasts and labile clastic minerals in red beds, hydrous ferrous oxide cements in red beds, or subaerial mafic volcanic rocks. Deposits of the Revett model are a silver-rich variant of the sediment-hosted copper deposits. Copper-bearing oxidized brines migrated into reduced, permeable quartzites to form roll-front-like, mineralogically zoned deposits at the redox boundary.*

### Placer Potential

Revett-type copper deposits are not generally auriferous, so the potential for associated placers is very low.

## **Skarn Gold Deposits** (Box and others, 1996)

*Skarns are metallic sulfide and oxide replacement deposits that occur in carbonate host lithologies adjacent to shallow plutonic bodies with metal-bearing hydrothermal systems (Einaudi and others, 1981). Pyroxene and garnet are the most important diagnostic skarn minerals. Skarn gold deposits are a subset of a spectrum of skarn types that are variously copper-, zinc-lead-, or iron-rich. Theodore and others (1991) recognize a class of skarn deposits of gold-bearing skarn if they have an average gold grade of at least 1 gram per ton and typical skarn mineralogy. They recognize two subtypes of gold-bearing skarns: gold skarn and byproduct gold skarn. They define gold skarns as skarn deposits where gold is the principal commodity, and byproduct gold skarns as deposits where gold had been or is being recovered as a byproduct. Only the gold skarn subtype is considered here, because byproduct gold skarns are primarily copper skarn and lead-zinc skarn, and these deposit types are considered elsewhere.*

*The main criteria used for this model are: (1) The deposits must have an average gold grade of at least 1 gram per ton, and (2) the mineral assemblage of the deposit must be representative of a skarn environment. Gold-bearing skarns are commonly the result of large-scale metasomatic transfer of components between hydrothermal fluids and predominately carbonate rocks. They are generally calcic exoskarns associated with intense retrograde hydrosilicate alteration. The carbonate bodies that host the mineralization need not be regionally extensive, but can be small local bodies that are widely scattered. The igneous rocks act as the heat source and, in most cases, the source of components for the hydrothermal fluids. Gold-bearing skarns can be associated with porphyry-copper or copper-molybdenum, polymetallic replacement, and polymetallic vein deposits. The median deposit for this model (Theodore and others, 1991) is quite small—213,000 metric tons at 8.6 grams per ton equaling 59,000 ounces gold.*

## Placer Potential

Deposits of this kind may have no placers, like the New World deposit near Cooke City, Montana, or be nugget-rich like the Gold Creek placer northwest of Deer Lodge, Montana. Many are known for coarse nuggets (e.g., Fish Creek placer, south of Butte, Montana) and unpredictable lode deposits. Some early miners became wealthy by panning.

The gangue rock is typically marble and intrusive rock that produces abundant black sand when eroded. Near Elephant Creek, Elk City, Idaho, egg-sized magnetite and hematite nodules are not unusual. Placer deposits from skarns may contain tungsten minerals, ilmenite, garnet, andalusite, hematite, and various other contact metamorphic minerals. These minerals often occur in such large amounts that concentration and separation of the valuable components become more complicated. Although the lodes are small and in pods, the placers are usually extensive. This is in part due to the extensive alteration of the lode deposit, which accelerates erosion. The size of the gold particles and the original mineralogy may also be major factors. The gold particles usually have a high fineness ranging from 880 to 930; copper may be an impurity.

Uneroded but heavily altered skarn lode deposits commonly become residual

placers. Some narrow bedding-plane skarns may appear to be placers in the field but on exposure are revealed to be lode/residual deposits. They can, however, be worked to extensive depths by conventional placer equipment. This type is common in western Montana, where limestone outcrops intruded by igneous bodies exist from Lincoln south to Dillon and form a 100-mile-wide zone of gold deposits that represents the majority of placer deposits in the state. The Fairbanks district of Alaska is another example of placers derived from a skarn gold lode deposit (Alaska Geological Survey, written communication, 2001).

## **Polymetallic Veins, Porphyry-Related** (Box and others, 1996)

*Porphyry-related polymetallic veins are quartz-carbonate veins with gold and silver associated with base metal sulfides. The veins fill near-surface fractures and breccias that are peripherally associated with hypabyssal calc-alkaline to alkaline intrusions (Cox, 1986b). The veins are commonly located in distal positions with respect to nearby porphyry-style hydrothermal cells developed over the tops of cooling plutonic bodies. They occur within wide propylitic alteration zones around the associated intrusive bodies and are commonly flanked by narrow sericitic and argillic alteration zones. If carbonate-rich strata are present, the veins may be associated with polymetallic replacement deposits. Vein mineralogy is typically zones with copper and gold closer to the associated intrusive body outward to zinc-lead-silver veins, with manganese-rich veins at the periphery. The median size of the individual porphyry-related polymetallic veins is quite small, with a median tonnage of 7,600 metric tonnes of ore with 2.1 percent zinc, 2.4 percent lead, variable copper, 0.13 gram per ton gold, and 820 grams per ton silver (Bliss and Cox, 1986).*

### Placer Potential

Deposits of this type have mixed potential to develop placers, similar in this respect to copper–porphyry systems. If the matrix is largely sulfidic, the subsequent placer deposits are quite limited. If an extensive oxide or quartz–gold zone is present, then extensive placers may be formed.

Examples of the former type are found in the Monte Cristo district, located east of Everett, Washington. These deposits have 20-ft-wide, polymetallic hydrothermal veins exposed at the surface. No known placer exists below these, but many talus slopes are made up of arsenopyrite boulders. In Alaska, significant placers from this lode type exist in the Nyac area (Alaska Geological Survey, written communication, 2001).

## **Skarn Copper Deposits** (Box and others, 1996)

*Skarns are metallic sulfide and oxide replacement deposits that occur in carbonate rocks adjacent to plutonic bodies with metal-bearing hydrothermal systems (Einaudi and others, 1981). Pyroxene and garnet are the most important diagnostic skarn minerals. Copper skarns are an end-member of a spectrum of skarn deposit types that are variously copper-, zinc-lead-, or iron-rich (Cox and Theodore, 1986). The deposits are associated with shallow, intermediate plutons, commonly those that are host to porphyry-style mineralization. The carbonate bodies that host the mineralization need not be regionally exten-*

*sive, but can be small local bodies that are widely scattered essentially throughout the map area. Copper skarns can be associated with porphyry-copper or copper-molybdenum, polymetallic replacement, and polymetallic vein deposits. The median size of a copper skarn deposit is 560,000 metric tonnes of ore with a median grade of 1.7 percent copper (Jones and Menzie, 1986).*

## Placer Potential

The potential for placer deposits derived from these rocks depends on lode deposit characteristics. If the copper contains gold in a sulfide matrix, then the potential for a placer is small. If the deposit is zoned so that the gold occurs separately from the copper sulfides, then a placer deposit may form. As with the gold skarn, accessory heavy minerals will be magnetite and possibly tungsten, garnets, and zircons from the source intrusive.

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# Chapter III: Data and Field Interpretation of Placers

# Reconnaissance and Deposit Mapping

Evaluation of a placer property requires that the mining engineer or geologist "see" below the surface. Given the literal impossibility of this task, any available tools must be utilized to predict the location and character of the deposit.

## Preliminary Search

Over the years, prospectors, geologists, and mining engineers have preceded present-day evaluators to nearly all mineralized areas. A few have looked specifically at the placer deposits, while most have looked at the adjacent bedrock geology. Historically, placer data were not collected for the purpose of understanding the placer deposits, but rather for academic interests or further understanding of the lode geology.

Before conducting field work, an evaluator must gather any available published and unpublished data. This is imperative. Old newspaper articles may contain pictures or references to the character of the gold, distance to bedrock, surface and subsurface water flows, underground workings, mining methods, and, although infrequently, accurate production numbers. These articles were usually not written to provide technical information; therefore, the data must be gleaned by inference or deduction. Operational problems sometimes noted in such articles may include short field season, excessive water, clay-rich zones, or numerous other issues. Most likely these would be the same problems current operators would encounter.

News articles or courthouse records may provide the names of local people who were present during production and who could share observations and experiences of the property. Observations such as gold size and shape, mineralized host rocks, bedrock textures and characteristics, overburden characterization, pay zone width and depth, unique features in the workings, and mining methods could provide valuable insight to the examiner while field work is being conducted.

Published works by the U.S. Geological Survey, U.S. Bureau of Mines, and State geological surveys often contain valuable data, but this information rarely pertains to the specific needs of placer projects. Reports of this kind more commonly evaluate the property in light of a given mining technique or the history of the area. Documents may, however, provide descriptions of bedrock and outcrop characteristics, as well as identifying structural controls and geomorphological features that could provide valuable hints to the depositional controls of the placer deposits and the sources of the gravels, gold, and other potentially valuable minerals. Older publications (1800s–1940s) commonly provide better descriptions than newer publications. Maps showing surface and underground workings and their locations may indicate mineralized zones that significantly influence the values found in the placer deposit, and deserve a closer investigation.

Aerial and satellite photographs and topographic maps may depict locations of deposits and potential sources of minerals that may not be obvious on the ground. These are also useful tools for identifying faults, alluvial fans, landslides, and other geomorphic features that could possibly influence the character and value of the placer deposit.

Unpublished works such as master's theses, symposium papers, and school and promotional reports often contain critical data that must be measured against field data and other material. This information may help in the process of deriving alterna-

tive solutions to placer evaluation problems or may provide critical data that will form the background for the interpretation of sample results.

Production records that are commonly available at State or Federal agencies are another valuable data source. In addition to quantities of past metal production, these reports may indicate the average fineness or purity of the gold, which can be a good source indicator (see Chapter II).

The previous years of production are also important in evaluating an area. For example, if a mine ceased production in 1942, it was probably closed by the War Production Board Order L-208 (October, 1942) rather than by economics. If the mine closed in 1940 or 1941, it may not have been able to secure either rationed supplies or laborers. From post-war until 1974, gold prices were government-controlled, but labor and material costs were not. The result was that placer mining was uneconomic, except for a few deposits. Mining activities during the middle 1930s reflected an increase in gold prices and improved availability of equipment and technology. Those mines that operated between 1872 and 1932 represented mostly subsistence activities.

# Interpretation of Geologic Data

## Deposit Mapping

Mapping develops visual tools that are essential to the understanding of a deposit. During this process the evaluator produces a collection of maps that show surface and subsurface characteristics of the deposit(s) on the property. Initially the mapping is confined to surface-accessible data, but during sampling the subsurface data will be added, both as maps and in the form of cross sections and long sections.

This portion of the evaluation has a two-fold purpose. The first is to ensure a sufficient understanding and knowledge of the deposit so that evaluators can make responsible decisions regarding sampling requirements. Until the sampling is completed, it is rarely possible to develop anything more than an informed guess. Second, and more importantly, evaluators gather sufficient information to understand the results obtained during the sampling process. Typically those results will not be uniform or predictable and may not make sense logically until thorough analysis of all the data gathered during this stage is complete.

Prior to the location and excavation of sample sites, evaluators must locate claim corners and establish side and end lines. They must map significant topographic and geomorphic features such as alluvial fans, stream boundaries, and benches and reference the claim boundaries. Lode mine workings, rock outcrops, changes in rock type, alteration, faults, and historical placer workings must also be depicted on this map.

Placer and lode deposit types and their boundaries must be identified and recorded. On the first cut, the evaluator is recording the observations that will become the working model of the deposit(s). Various placer deposit types most likely overlap and cover each other; each type of placer deposit must be identified so that a sampling program can be designed for adequate testing of each deposit. During sampling, the mapping can be modified to reflect new information, but it will evolve from the baseline data.

Developed maps may be exhibited as layers in a CAD (computer-aided drafting) or GIS format or as individual maps if drafted by hand. These maps usually include:

1. Geographic location: Primary access routes and recognizable landmarks such as principal towns. The scale should be chosen to indicate the location and the most

reasonable paths of access. Also helpful are locations of major drainages and any other easily recognizable features. This map is usually available or can be modified from published sources.

2. Regional geology: Lithology, structure, bedding, lode mines, geomorphological features and surficial geology (i.e., moraines, landslides, etc.), placer deposits, topographic contours, and drainages at a scale of 1 in = 62,500 ft or larger, covering a radius of 3 to 5 miles around the deposit. It is important to identify all major factors that created, controlled, or influenced the placer deposit, including mineralized structures, geomorphological features, and bedrock lithology. In many areas of the U.S., this type of map will be available from published sources.
3. Deposit Map I: Large scale, such as 1 in = 50 ft, claim boundaries, deposit boundaries, topography, boundaries of historical workings, local geology that extends perhaps 1,000 ft outside the claim boundaries (i.e., rock types, strikes, dips, weathering characteristics, and structure), lode mine(s), buildings, roads, timber, streams, wetlands, ponds, tributaries, and geomorphologic features.
4. Deposit Map II (Overburden Thicknesses): Deposit boundaries, claim boundaries, boundaries of historical workings, sample sites, overburden-thickness isopachs, large scale such as 1 in = 50 ft (compiled after sample processing).
5. Deposit Map III (Pay-Zone Thicknesses): Deposit boundaries, claim boundaries, boundaries of historical workings, sample sites, pay-zone-thickness isopachs, large scale such as 1 in = 50 ft (compiled after sample processing).
6. Deposit Map IV (Pay-Zone Grade): Deposit boundaries, claim boundaries, boundaries of historical workings, sample sites, pay-zone-grade isopachs, large scale such as 1 in = 50 ft (compiled after sample processing).
7. Cross Sections: Where possible, drawn along each sample line showing the bedrock–alluvium contact, gravel size and angularity, gold characteristics and pay zones, surface shape, bedrock–gravel contact (valley profile), stream location, soil thickness, overburden thickness, and bedrock and pay-zone characteristics at a horizontal scale equal to the scale of the deposit maps and a vertical scale suitable to depict the detail available. The location(s) of the surface trace of the cross sections should be drawn on Deposit Maps I, II, and III. The cross sections are used to depict the interrelationships between the sample sites. If they are accurately constructed, items such as multiple depositional events will likely become obvious. If adequate detail is provided, it will be easy to see overprinting of deposit types and economic boundaries of the deposits.
8. Longitudinal Sections: Designed to bisect the pay zone or zones for the length of the deposit. They should reflect physical changes in bedrock profile, overburden and pay-zone thicknesses, grade, bedrock, and surface gradient. Horizontal and vertical scales will usually be the same as those used for the cross sections. Numerous longitudinal sections may be constructed if clarification is needed. A surface trace of each section should be indicated on Deposit Maps I, II, and III. Through this exercise, relationships between cross sections will be clarified, and problems will become apparent. Radical bedrock elevation changes will be easily seen, as will the structures contributing to the deposit.
9. Stratigraphic sections of each sample site (details in Chapter IV) provide details without clutter (i.e., 1 in = 5 ft or larger).

Maps and sections produced through the use of computer applications may result

in clear, easy-to-understand products. However, no amount of computer manipulation of information and presentation format will compensate for bad field data and samples that are not representative.

After the existing reference and field data have been compiled, the difficult task of interpretation begins. What may be a valuable discovery of a placer deposit by an experienced evaluator may only look like another pile of rocks to the untrained eye. Experience, interest, and curiosity are important in solving placer deposit problems.

Each piece of information may be independently important for a number of reasons. For instance, brittle and hard bedrock that is fractured and dips perpendicular to the gradient of the drainage may have been important in trapping gold and forming placers. However, if it is tough and difficult to penetrate during excavation, it will be difficult to release the gold trapped in the fractures and cavities, and recoveries will be low. If the bedrock dips parallel to the drainage gradient, trapping structures may not be present, and the valuable minerals may have drifted down-gradient to the first geologic change (e.g., fault, rock-type change, or topographic constrictions) and concentrated there. The likely result would be a zone mostly devoid of values followed by an area of increased gold concentration. A soft argillitic bedrock or bedrock with a high degree of alteration may form a thin zone of enrichment near the contact but may not allow gold particle infiltration. Mining this type of bedrock may result in reduced production and recovery and increased costs due to clay content. Lag gravels deposited on bedrock may function similarly to a jagged bedrock surface and collect values in the space between the cobbles. A boulder veneer overlying bedrock may also collect gold in the same way as a jagged bedrock surface (figure 3.1).

Structural features such as faults may be indicated by elongated ridges and saddles, stream-gradient changes, changes in valley profile and configuration, abrupt changes in stream direction, springs, landslides, and changes in vegetation. A resis-

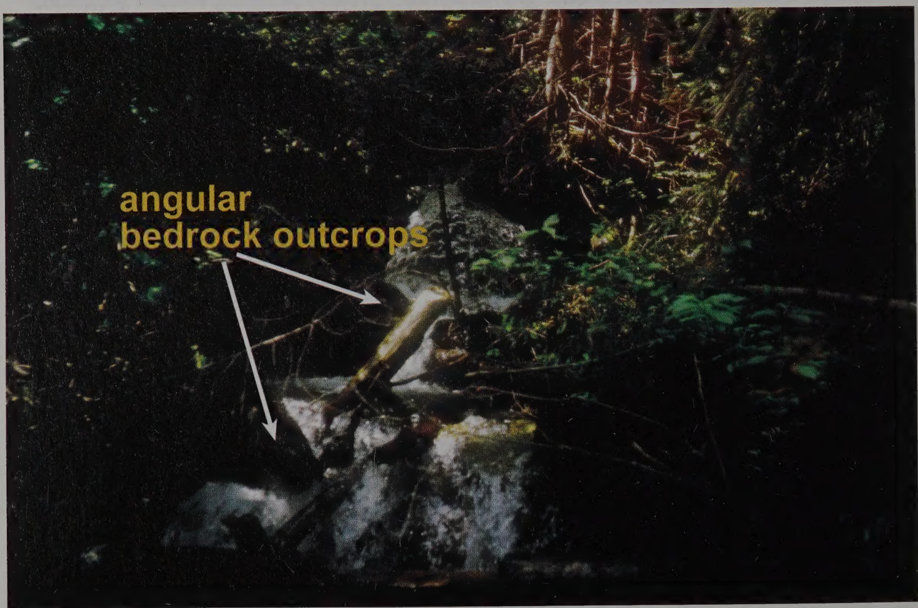


Figure 3.1. Cascading water through bedrock plunge pools often creates low-volume high-grade placer deposits.

tant quartz vein that cuts across the drainage (figure 3.2) may form a dam or nugget trap in the drainage. The quartz vein may also be a gold source, which will complicate the interpretation. A change in bedrock character from soft and erodible to hard and resistant may also dam or trap nuggets if the harder material is located on the downstream side. Faults may disrupt drainages and create dams that result in high-grade pockets. Landslides may also create lakes or ponds in the drainage during the depositional phase which later become covered. If displacement occurs along a fault, plunge-pool deposits may develop downstream from the fault line. These placer deposits may be quite rich if the fault is also the mineral source and heavy minerals become concentrated in the pool (figure 3.3).

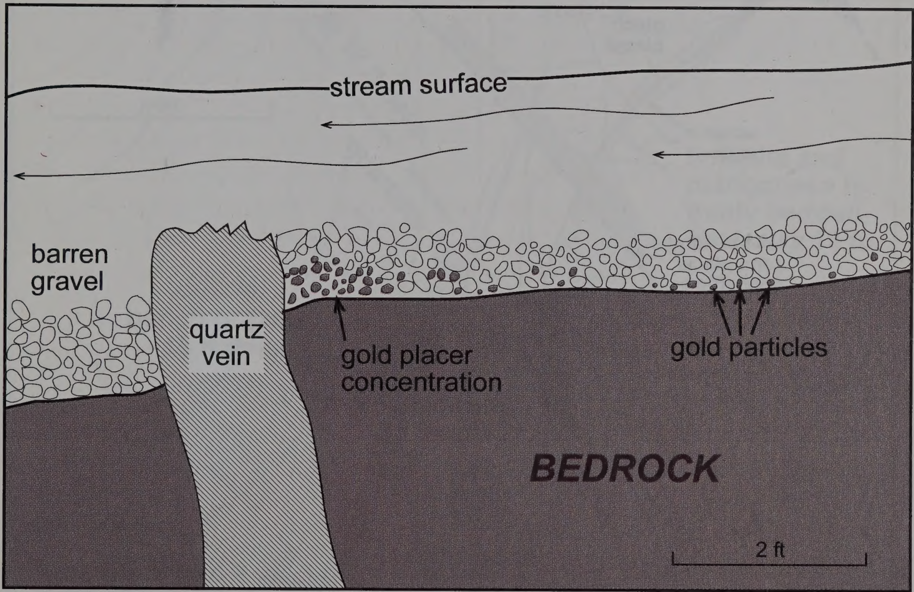

Figure 3.2. Longitudinal section showing vein-controlled gold trap.

Faults often control the locations of drainages; drainages commonly make a distinct bend to a predictable trend when aligning along a structure (Porter and Skinner, 1987). A fault may cause the main stream channel to be localized on only one side of a valley and thus control deposition of placers within the valley.

Dikes or faults may also create wide, flat areas in drainages. Gold tends to drop out at the gradient change where the velocity of the stream decreases abruptly. Where a narrow canyon is created, the water tends to travel at higher velocities. These zones are typically scoured and will contain only the coarsest pieces of gold and the largest boulders. If a drainage results from erosion of a fault zone that has been altered and mineralized (figure 3.4), it may host a residual deposit and be overprinted by a lag or transport deposit.

Fault intersections are favorable locations for lode mineral deposits. If such an intersection is in or near the edge of a drainage and the gradient of the drainage is not very steep, there is a distinct possibility that the placer deposit will not extend very far downstream from the source.

Important data may be overlooked if the evaluator is focused on a single deposit in a placer system and ignores other nearby placer occurrences. For example, during

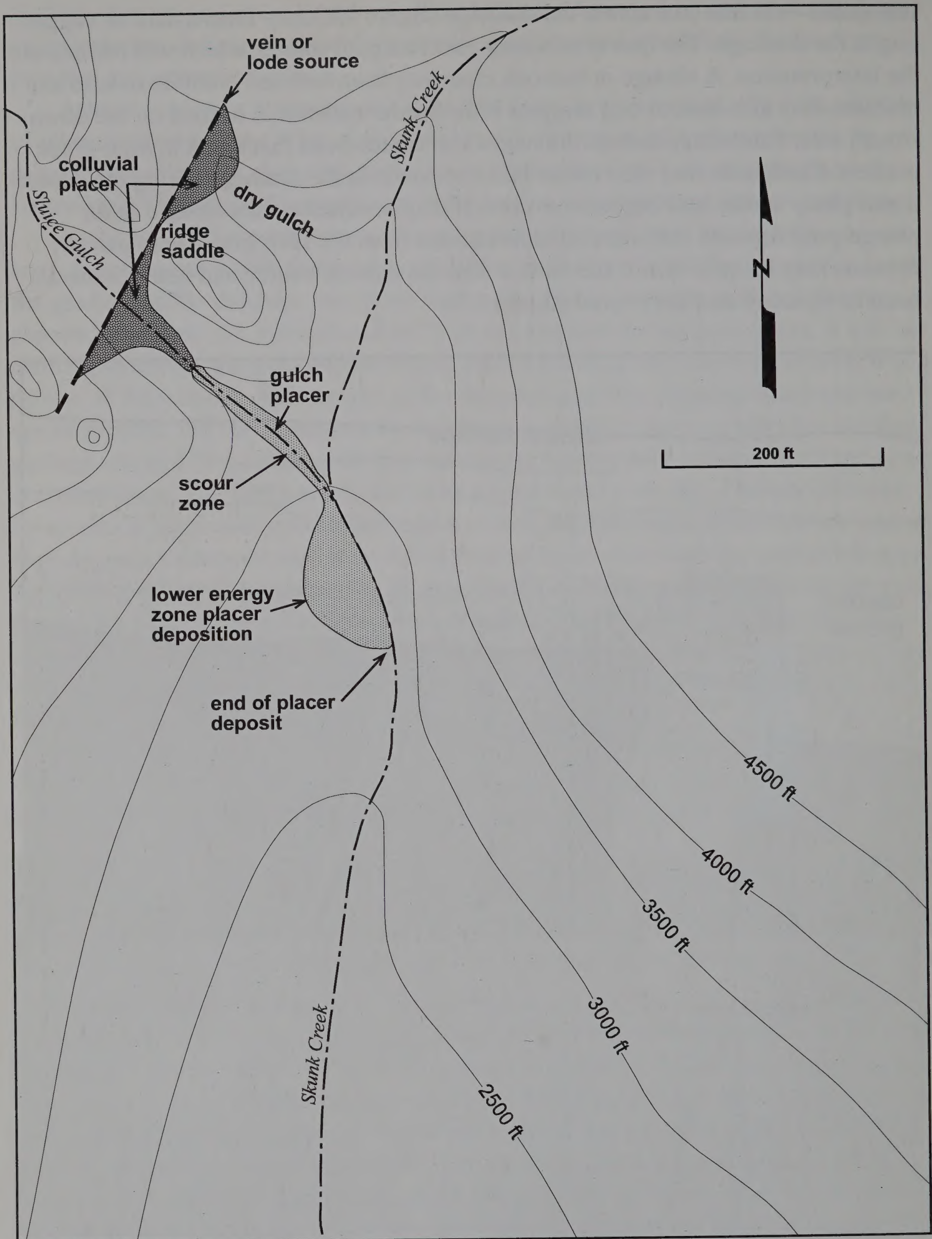


Figure 3.3. Placer source with a low-gradient depositional area.

the examination of adjacent drainages, the evaluator may observe that bench deposits begin at a common elevation, which indicates that possibly a lakeshore existed at that elevation at one time. Lode mines located on a linear trend that cross-cuts ridge saddles and drainages may indicate a mineralized structure that could be the source of placer minerals in multiple drainages. Placer deposits located only on the down-gradient side of a range-front fault may indicate that the fault or the lower block is the primary gold source.

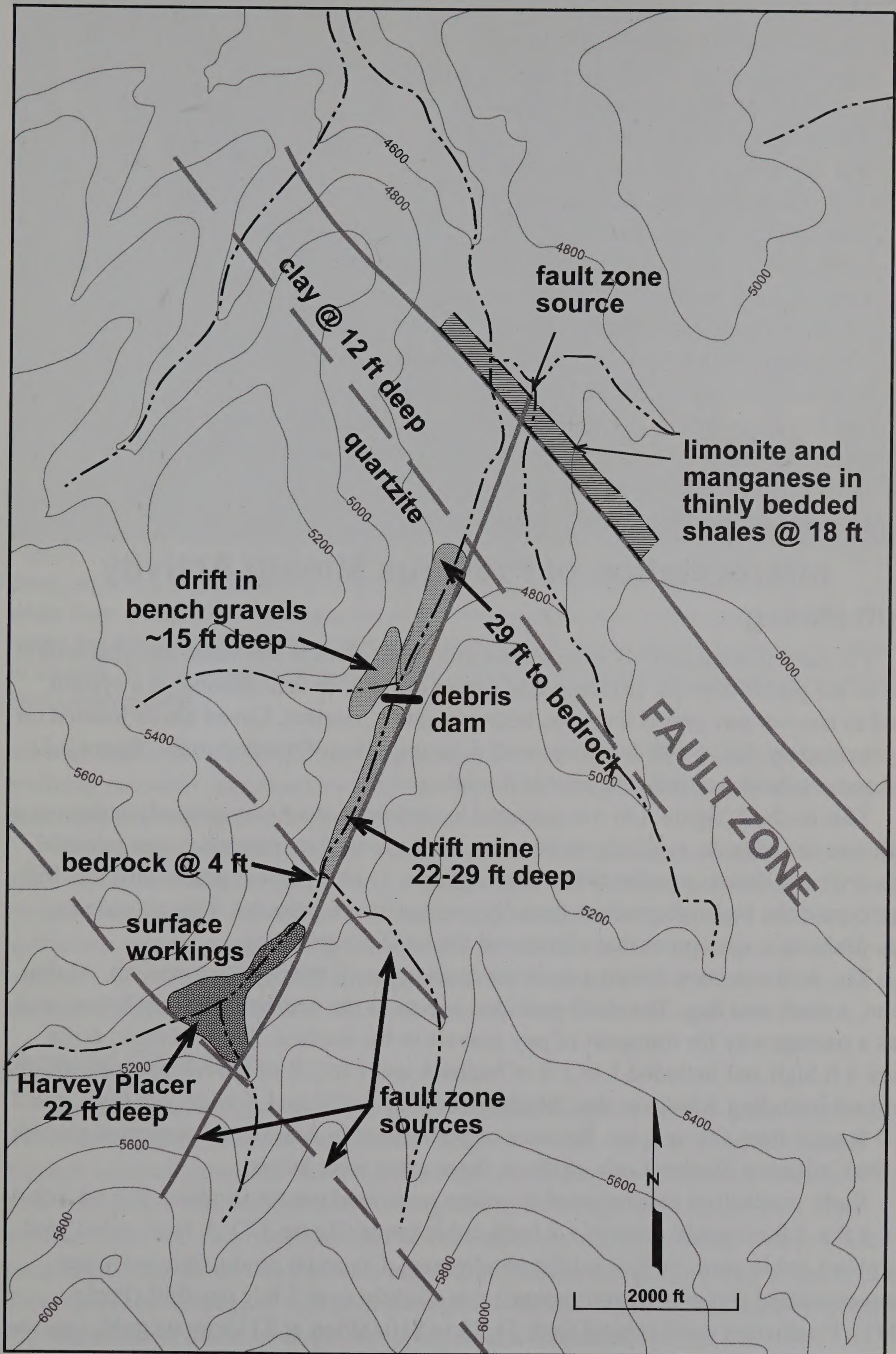


Figure 3.4. Gold placers and controlling structures (Sauerkraute Creek near Lincoln, Montana).

## On the Ground

When the evaluator arrives on site, there are several questions that must be addressed to properly evaluate the deposit:

1. Has the deposit experienced previous mining activity?
2. If so, what mining method was used?
3. Why was this method used?
4. Was the method used competently?
5. How much of the deposit remains?
6. What are the depositional controls?
7. What is the likely lode source(s) of the placer minerals?
8. What is the proximity to the lode source?
9. What are the deposit characteristics?
10. Is the gold concentrated in a specific horizon or interval?
11. How much revenue can this property generate?
12. Are there any special problems related to handling or recovery?
13. What size and type of machinery would operate most efficiently?
14. What are the reclamation requirements?
15. What are the environmental considerations?

# Interpretation of Previous Mining Activity

## Drift Mining

Previous mining activity can contain important clues to the value and characteristics of the placer deposit. Underground placer mining, or drift mining, is a system used to recover pay gravel from the bedrock–gravel contact. Caved shafts located on approximately 50- to 100-ft centers with adjacent piles of washed rock (figure 3.5) and some subsidence indicate past drift mining.

This method (figure 3.6) was initiated by sinking a shaft (dry ground) or driving a drift into the hillside, typically in bedrock, so that portal maintenance was minimal. The drift was driven parallel to the drainage on a 1- to 2-percent grade until the drift intercepted the bedrock gradient (usually greater than 6 percent). This provided a free-draining access point that eliminated the need for pumping.

The drift was then driven across the drainage until the pay zone was hit. At that point, a shaft was dug. The shaft provided access to the bedrock and ventilation, and was a passageway for transport of pay gravels to the surface. Many of these drifts were 4 ft high and included 1 to 2 ft of bedrock and 1 to 2 ft of gravel. Each set of timber (not including Alaska or the "Mother Lode") was 2½ to 4 ft wide, 4 ft high, and 2 to 4 ft apart from the next set. Because of permafrost in Alaska and cemented gravels in the California Mother Lode, drifts in these areas were larger.

Early production was reported in values recovered per set (timber). If a set was 4 ft x 4 ft x 2 ft, it would contain 1.2 bank cubic yards (figure 3.7). A bank cubic yard (bcy) is 1 cubic yard ($yd^3$) of undisturbed gravel. Common production per miner (non-cemented and non-frozen ground) was slightly over 1 bcy per shift (Peele, 1941). Production costs ranged from \$1.75 to \$10.00/ton at \$35/troy oz gold, equivalent to approximately \$26.25 to \$150.00/$yd^3$ at \$350/troy oz gold.

According to Gardner and Johnson (1935), "bedrock must average at least \$2.50 per ton at \$35 gold to be mined profitably by drifting." In this report, equivalent val-

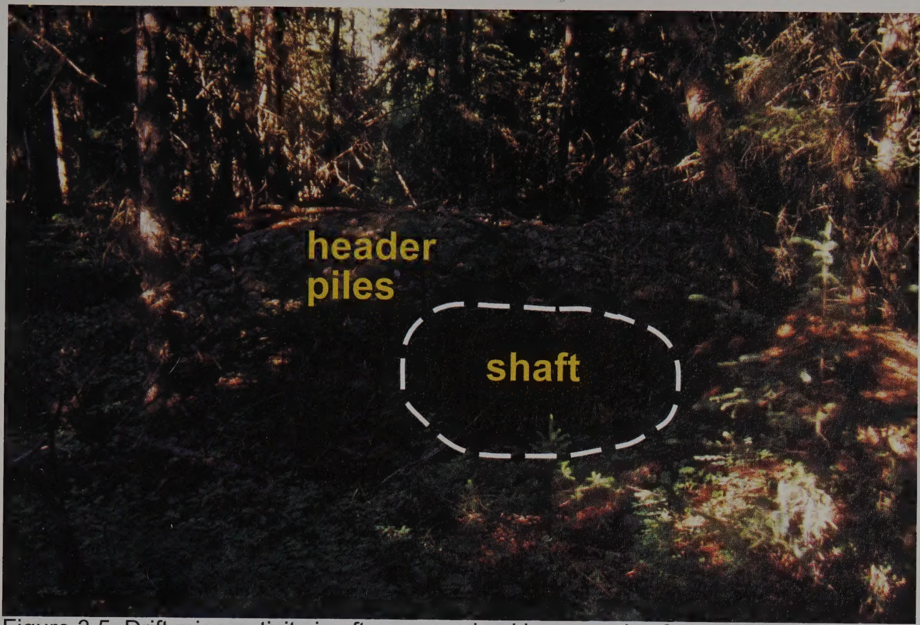

Figure 3.5. Drift mine activity is often recognized by mounds of washed rock (header piles) adjacent to depressions in the ground. These header piles are usually 50–100 ft apart over a considerable distance. Post-mining vegetation and weathering often make the mounds and depressions difficult to see, and sometimes even more difficult to identify. This is especially true in areas of heavy vegetation and forests with significant undergrowth.

ues and costs indexed to $350/troy oz gold is done to allow the reader a means of realizing potential opportunities worthy of exploration and are not provided to equate economics, as costs are not typically linear with time.

The width of operations in non-cemented and non-frozen ground typically ran about three timber sets wide, or about 12 ft. Higher values and tighter ground allowed a more complete recovery of the resource. In many cases, with the use of today's machinery and techniques, miners would find that profitable pay zones remain on either side of the old workings. However, if the drift mining followed a distinct channel or pay streak, the values remaining on either side of the workings may be minimal or even nonexistent.

## Ground Sluicing

Ground sluicing is a method whereby ditches transport surface water to places where steep gradients allow the water to strip overburden and process pay gravel through headwall erosion. These systems are typified by narrow, linear channels where the sluice box was located down-gradient of the ground-sluiced area. The washed rocks were stacked on either or both sides during processing. Many times, sampling of the sluice ways reveals high values on the surface (>1 troy oz gold/yd$^3$). This represents leakage of fine gold through cracks and edges of the sluice. Therefore, it is important to know what the sampling results represent.

The sequencing of ground sluicing (figure 3.8) may be deceptive because the worked area may appear to be mined out, even though as much as 15 ft or more of gravel may be left intact. Operating costs for this type of mining were typically based

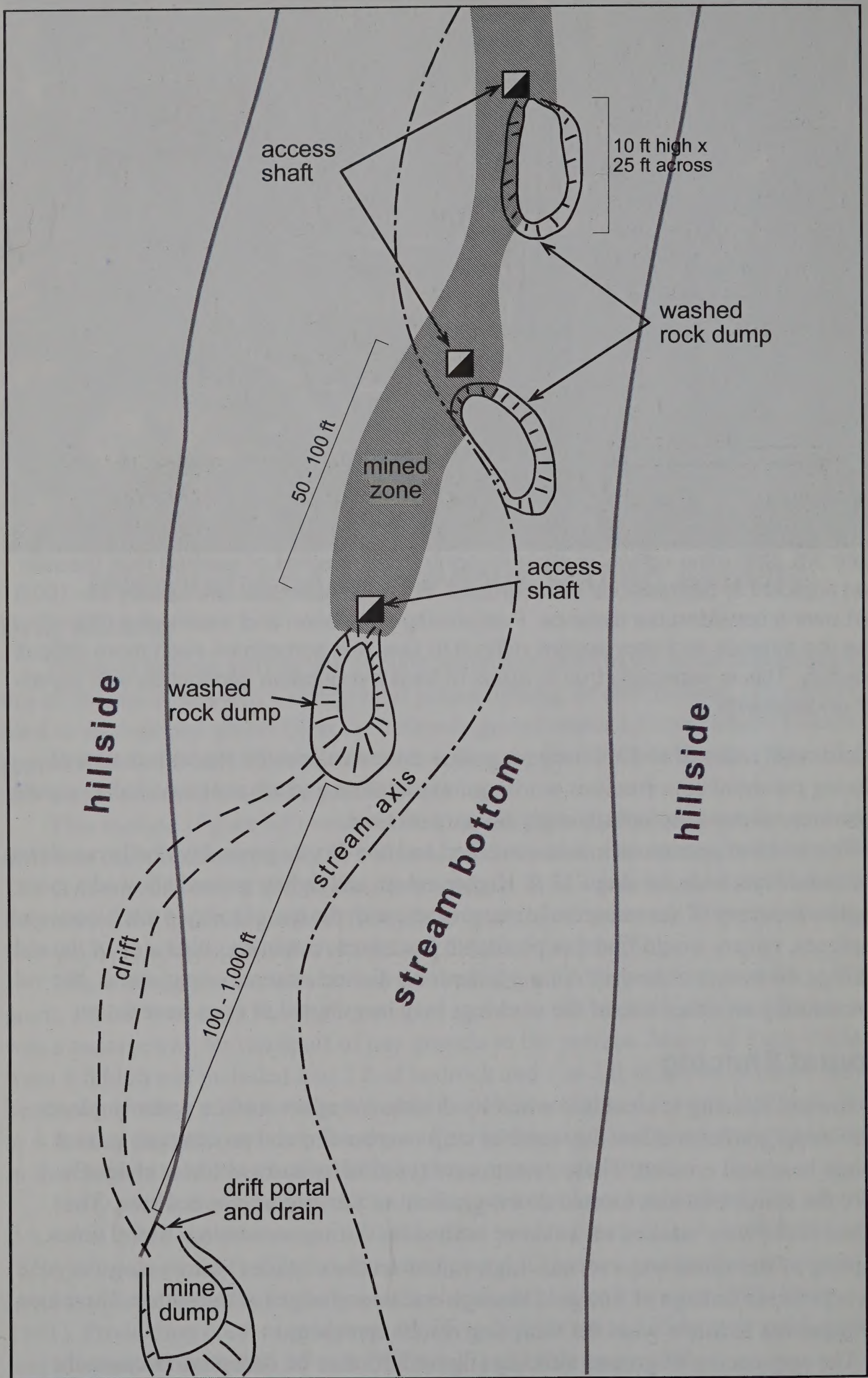


Figure 3.6. Drift mine development.

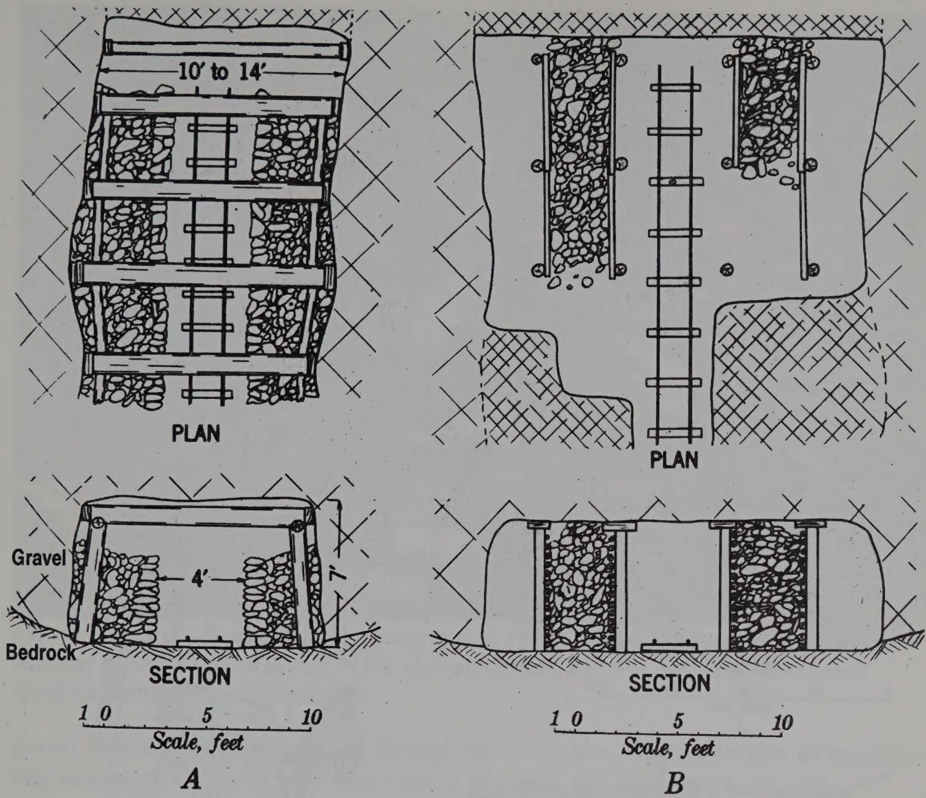


Figure 3.7. Breasting methods in narrow channels. A, advancing from shaft, Dakota mine, Rivulet, Montana; B, retreating to shaft, Townsend and Hornbrook mine, Hornbrook, California (Gardner and Johnson, 1935).

on the miner's time required to control the water and move rocks through the sluice box (figure 3.9). Most operations have reported costs less than \$0.30/yd$^3$. Values reported for this method rarely exceeded \$0.50/yd$^3$ at \$35/troy oz gold (Peele, 1941). At \$350/troy oz, ground-sluiced deposits may not be economically attractive unless values richer than \$5.00/bcy exist below the washed material.

If a deposit had inadequate water, contained tightly packed rocks, and/or had a shallow gradient, the ground sluicing was augmented by booming (rushing). In that method, a dam was built with an automatic gate that discharged a wall of water (figure 3.10) down the valley at periodic intervals. This allowed the movement of larger rocks and more overburden than with a smaller continuous flow of water. The initial construction costs were higher, but it became the method of choice in many districts. In these mining districts, the potential for additional values may still exist below the worked ground. If the first few test holes indicate the ground was previously worked to bedrock, the potential of the area is greatly reduced, and the rest of the project may be abandoned. Many recent operators have indicated an inability to find sufficient remaining reserves in a ground sluicing district (Richard Beeman, 1997, personal communication). The deposit must be tested to determine the potential. Because of

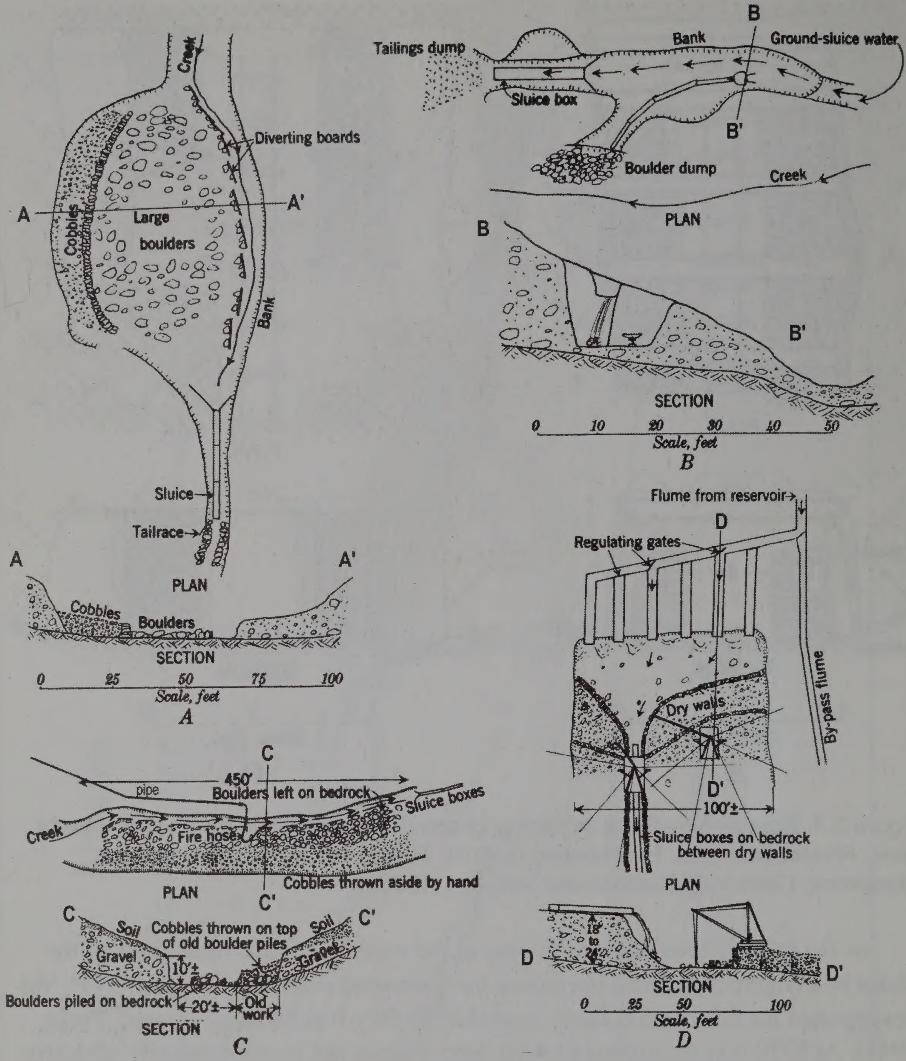


Figure 3.8. Layouts of ground-sluice mines. A, Ravano mine, Laurin, Montana; B, Rundle mine, Blackhawk, Colorado; C, Camp Bird mine, Laurin, Montana; D, Harvey mine, Lincoln, Montana (Gardner and Johnson, 1934).

procedural requirements, government evaluators must complete the evaluation regardless of early findings.

## Hydraulicking

Hydraulicking is the process of excavating gravel with high-pressure water. The water is gathered at a higher elevation, transported by ditch or flume to a site near the deposit, and then funneled through a high-pressure line to a lower-elevation nozzle. At this nozzle, hydraulic head provides a high-pressure stream capable of rapidly eroding gravel from the deposit while maintaining enough volume to carry the gravel and gold slurry to and through a sluice box where the gold is recovered. All of the

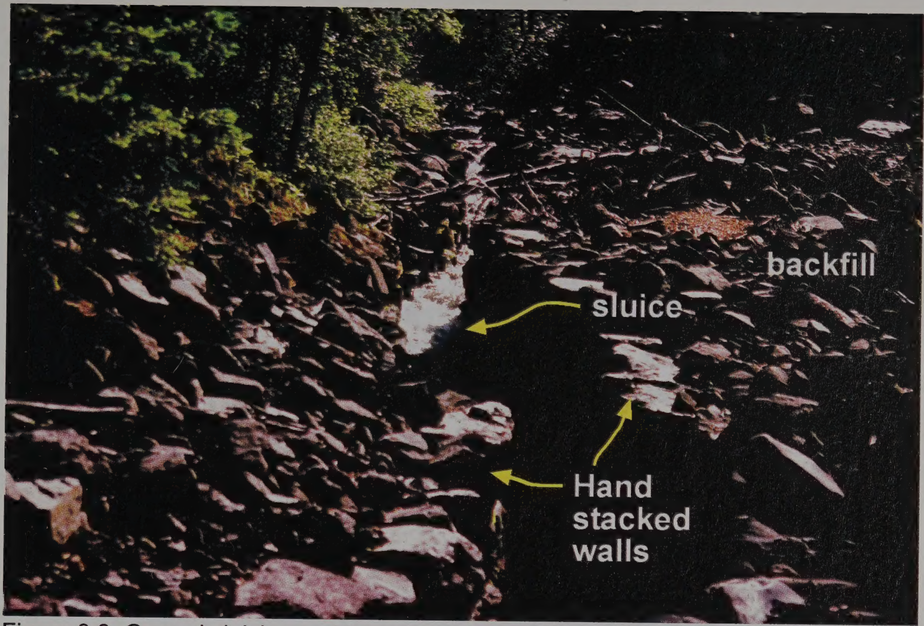

Figure 3.9. Ground sluicing and booming may result in spectacular walls of hand-stacked rocks. The sluice was in the stream bottom and the oversize rocks were hand-tossed behind the rock wall.

gravel (waste and pay) is washed through the sluice box, which provides an opportunity to capture all placer gold in the sluice (figure 3.11). Recovery losses are influenced by the viscosity and density of the slurry and shape and size of the gold particles. Losses are primarily -60 mesh gold particles.

Characteristics of a hydraulicked deposit include prominent high walls (figure 3.12) that commonly have an arcuate or a scalloped shape. Boulders and cobbles border the sluice where they were picked out of the box and tossed aside. Old pressure pipes with loop tabs for wire connection on the ends were commonly left as debris. Samples taken at the foot of the high wall may contain a concentration of nuggets due to their tendency to settle out of the slurry before entering the sluice. Due to leakage through the cracks in the old wooden sluices, enhanced grades may be encountered during sampling in the sluiceways. These enrichments tend to be primarily of interest to hobbyists; they lack enough volume to be of interest to commercial operators.

If the bedrock was tight (unfractured) and undulating, it is unlikely that significant economic values remain in either the bedrock or the sluice tails. Changes in viscosity of the feed in the box through-feed rate commonly resulted in losses of fine gold. Sampling of previously mined areas usually produces marginal values, but multiple sample sites should be selected to verify the evaluator's judgment.

Operating costs of hydraulic mining ranged from \$0.04 to \$0.25/yd$^3$ during the 1930s when gold prices were at \$35/oz (Peele, 1941). This allowed processing of very low-grade gravels at minimal costs. If sufficient water and enough elevation change to develop adequate hydraulic head were available, hydraulic mining was usually the least expensive option. The method was especially effective in cemented gravel or areas of deep overburden, but it required enough relief to allow tailings disposal. However, recla-

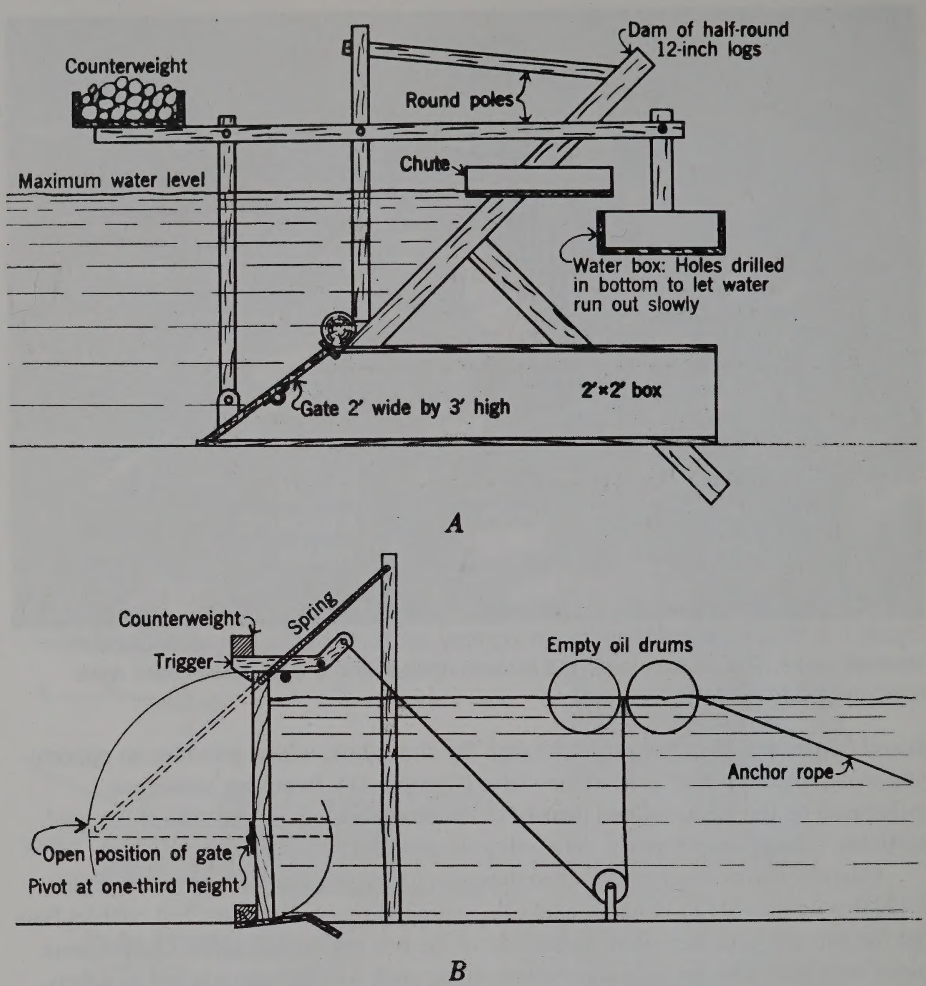


Figure 3.10. Two types of automatic gates for booming. A, gate used at Bennet mine, Rivulet, Montana; B, gate used at Harvey mine, Lincoln, Montana (Gardner and Johnson, 1934).

mation and environmental costs were a minor concern at the time. Reclamation and sediment-control costs today would certainly demand higher break-even grades.

## Dry-Land Dredging

Operations of this kind used derricks, cableways (figure 3.13), inclines, and mechanical excavators. Each method of operation utilized machinery to excavate pay gravels and then place them in a wash plant to concentrate the gold. The first three methods produced large piles of washed rocks from a stationary wash plant; they were used only in moderately shallow deposits (<30 ft) with easily excavated bedrock in ground that was loose and free of any large boulders (Peele, 1941). From above, a group of these pits may look like pearls on a string. Although these techniques were used for placer mining in the 1930s, it is uncommon to find them used in that capacity today. However, dry-land dredging is now fairly common in gravel pits that have shallow ground water.

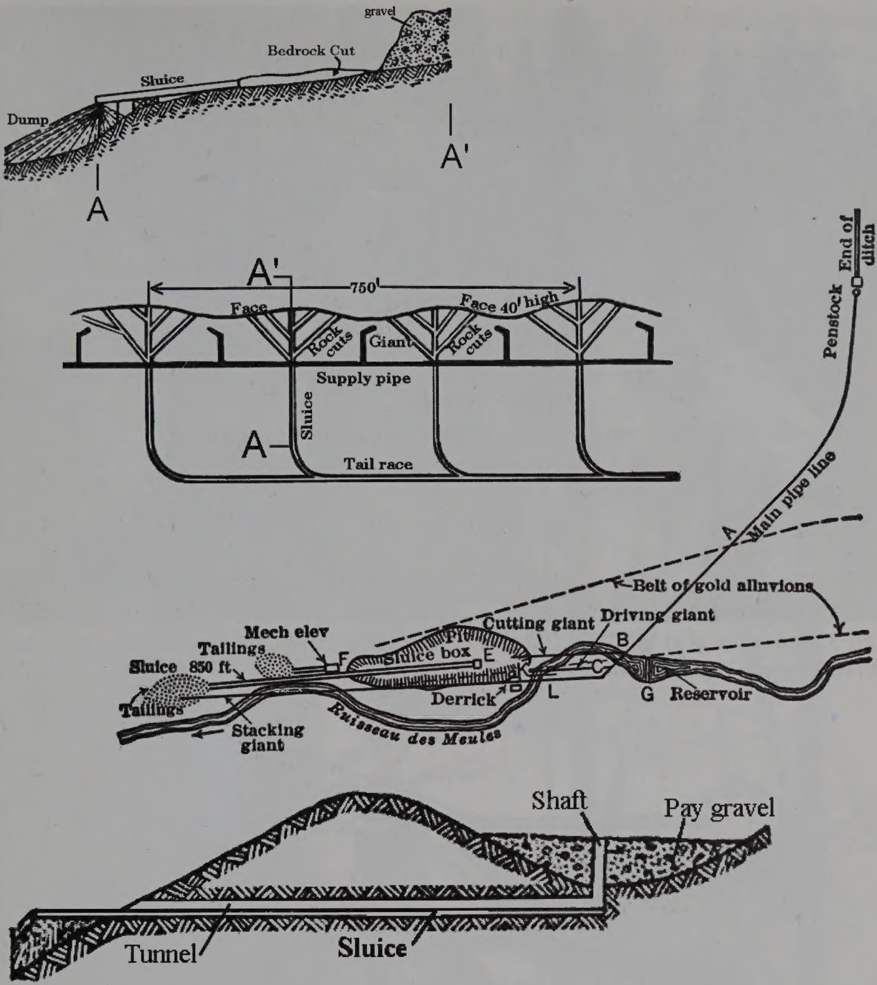


Figure 3.11. Hydraulic mines (Peele, 1941).

High-grade, low-yardage resources may still remain in pits that were excavated while flooded, because of the inability of the operator to see where he was mining. However, the large volumes of waste material that exist between the remaining resources may deem the deposit uneconomic for the foreseeable future.

Indicated operating costs of these systems ranged from \$0.45 to \$0.60/yd$^3$ at \$35/troy oz gold (\$4.50 to \$6.00/yd$^3$ at \$350/troy oz gold; Peele, 1941). Costs have been recorded up to \$1.32/yd$^3$ at \$35/troy oz gold, or \$13.20/yd$^3$ at \$350/troy oz gold. While looking at these deposits today, the evaluator can assume the value of the recovered gold was higher than the operating costs, and therefore the areas may be worth testing.

A popular system that has been used since the 1930s is the combination of a track-driven dragline and a dry-land dredge (land-based wash plant). The common sequence of gravel handling in the 1930s was to cast the overburden on virgin ground on either side of the cut and wash only the material contained in the pay zone (figure 3.14). The

Figure 3.12. Highwall in Malakoff Diggins State Historic Park, California. This was the North Bloomfield placer mine in the late 1800s.

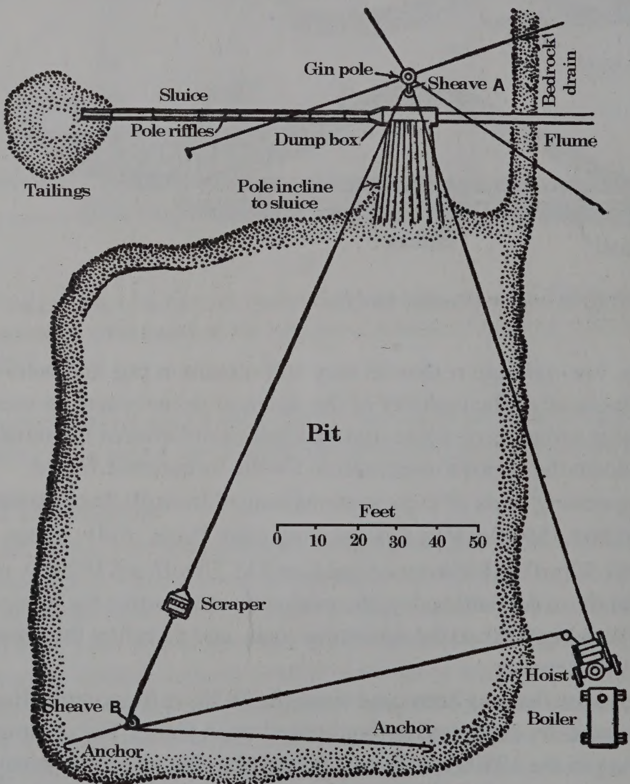


Figure 3.13. Slip scraper dragged up incline (Peele, 1941).

primary evidence that indicates a site was mined this way is the large, often heavily vegetated silt-rich spoil piles on either side of the cut. These will be characteristically hummocky with side slopes at the angle of repose. The center of the cut will have conical piles of washed rocks roughly 15 ft apart (peak to peak). This reflects the horizontal distance between the sheave pulley on the boom end and the closest point at

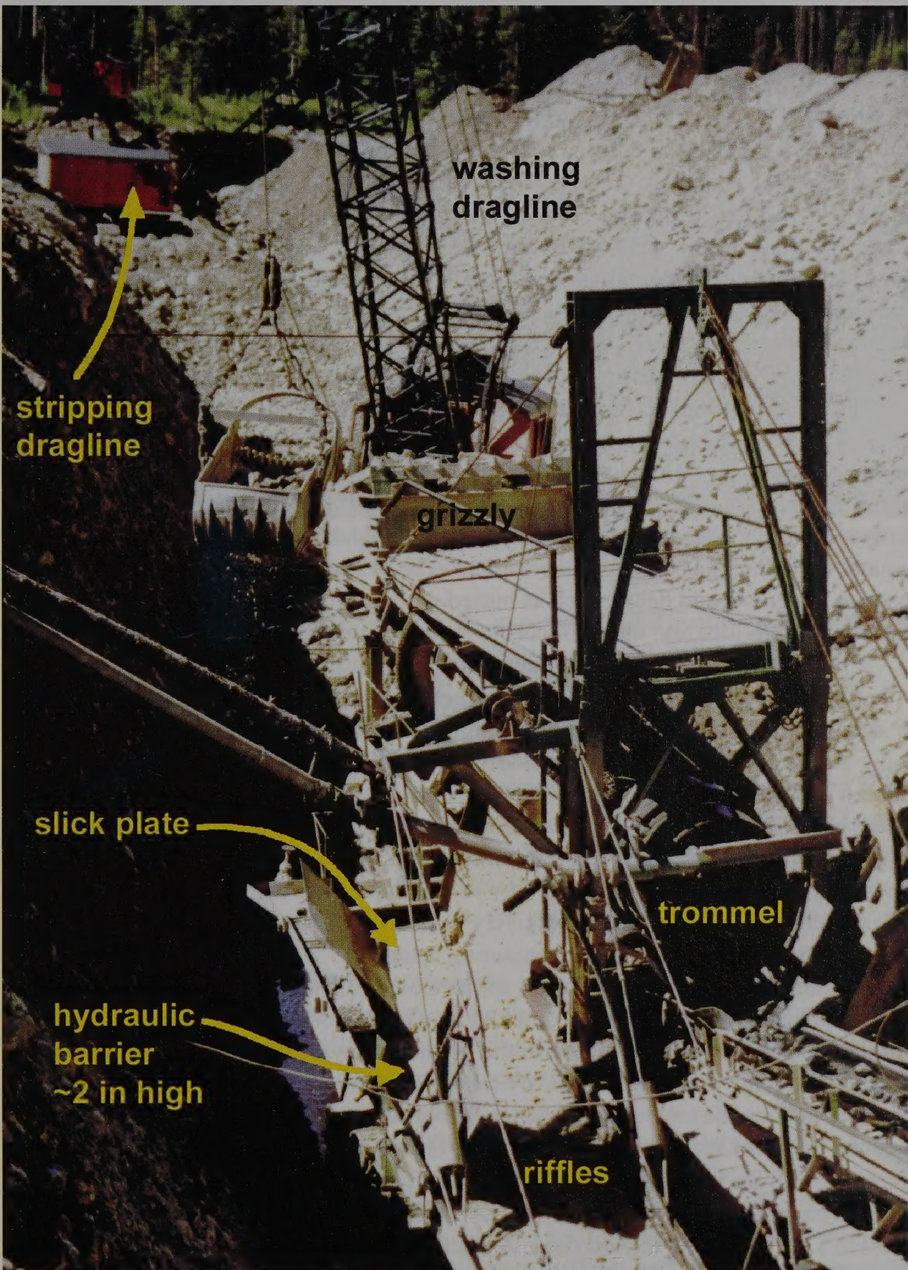


Figure 3.14. Sauerkraute placer mine near Lincoln, Montana. A two-dragline operation for mining a pay zone 29 ft deep.

which the bucket can approach the dragline. It is also the distance the dragline moves up-gradient each time the cycle is repeated. The controlling component of this distance is the size of the machine, specifically the length and angle of the boom.

The sequence of mining consists of pre-stripping the overburden, washing the pay gravel, and moving the dragline. The area that is processed each time is called a set. If the deposit was poorly tested and/or the break between the overburden and pay gravel was difficult to distinguish, high-grade values may be found at the top of the overburden piles. If the wash plant screen was too fine, the conical piles of washed rocks in the cut may contain many "oversize" nuggets. However, these sites will rarely contain enough remaining gold-bearing material to justify reprocessing.

The only significant potential resource remaining will be the virgin ground under the spoil piles, or possibly the bedrock surface if it was irregular and too hard to be mined with the dragline bucket. Modern recovery of resources discovered in this type of bedrock depends on operators having suitable equipment available for excavation and washing. If the old workings contain several adjacent rows of spoil piles, this probably indicates multiple cuts by the operation. The overburden of succeeding cuts was placed over the washed rock of the previous cut. Only the outside spoil piles have any reasonable potential of covering virgin ground.

Shovel fronts were interchangeable on many of the draglines in the period from 1930 to 1950. Hard bedrock and boulder pavements may have been processed using these cable shovels after the ground was pre-stripped. Testing may reveal bucket teeth marks in the bedrock if the test hole is large enough. If the placer gravel had no overburden, there is a chance that no spoil piles exist, which indicates that all of the ground, including the soil, has been washed. The evaluator must depend on void space in the gravel and debris such as buried garbage or wood to determine the limits of previous activities and their effects on any remaining resources.

A popular variant of this method was the substitution of the dry-land dredge with a floating wash plant (figure 3.15). In this method, the gravel was excavated underwater and the degree of success depended largely on the operator's sense of touch. Hard-to-dig zones containing clay and boulders may remain under the waste. The operators found it difficult to keep track of where the bucket actually was during mining because it tended to deflect from resistant ground. The buckets do not have the same digging characteristics or dig as well underwater as they do in dry conditions. These previously mined areas may show spotty values that reflect the inefficiencies of previous operations. However, they most likely will not demonstrate sufficient reserves and grade to justify mining of the remaining resource.

In drainages that have significant spring floods and that were processed with a floating plant from the grassroots down, it may be difficult to verify previously worked ground. The only evidence in the drainage may be the pond where the operators quit, although this may also have been filled by stream-carried sediments. Other evidence may be the anchor points where cables were fastened to trees and deadman anchors, but these are more difficult to find. Operating costs of these types of operations ranged from \$0.08 to \$0.35/yd$^3$ at \$35/troy oz gold (Peele, 1941). A reasonable break-even grade for operations of this type at \$350/troy oz gold would range from \$2.50 to \$3.50/loose cubic yard (lcy). A truck-excavator operation in 20 ft of overburden will cost about \$4/yd$^3$, if no significant stripping is needed.

Analysis of economic potential of these types of previously mined areas depends

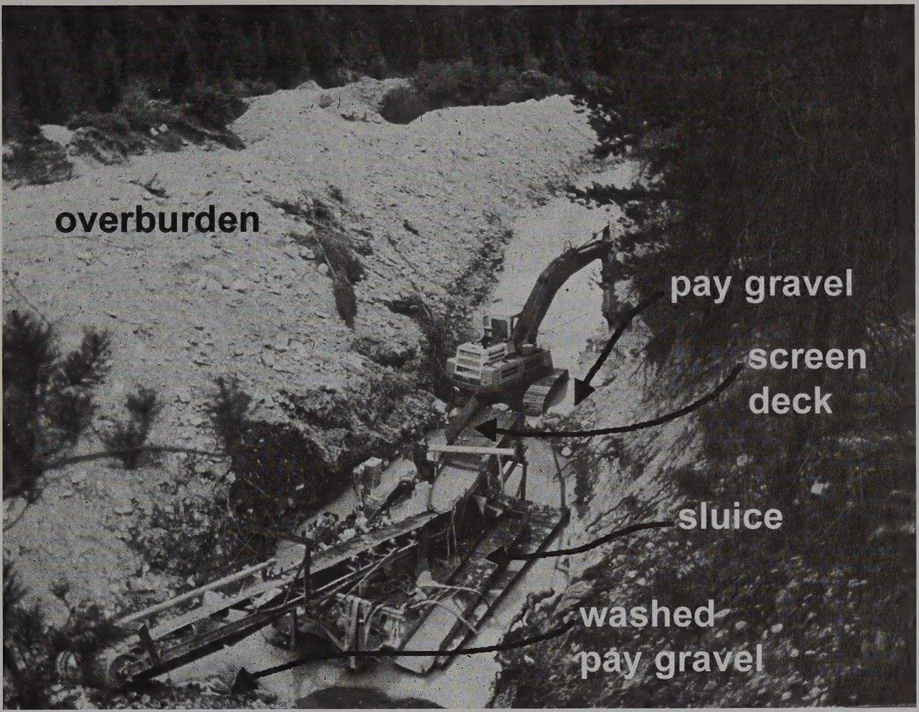

Figure 3.15. The Hughes Creek placer mine (near Darby, Montana) utilized a floating wash plant and excavator. The overburden was stripped with a 2-yd³ dragline.

heavily on the evaluator's observation skills, experience, and quality of notes, especially during the sampling process.

## Chain-Bucket or Bucket-Ladder Dredges

Floating dredges of many assorted sizes and capacities have operated in the United States, beginning prior to the 20th century and continuing through the 1950s. Many still exist in operational condition in Alaska, and many are producing in foreign countries. These self-contained units work with few personnel and at extremely low cost. Operations in the late 1930s reflected costs ranging from $0.20 to $0.26/bcy (overburden plus pay gravel). In 1981, costs for an operation in 98 ft of gravel were reportedly $1.20/bcy (Lewis, 1984).

Churn drill results are commonly available on properties that were explored in the 1930s. However, these reports often provide only the total amount of gold recovered over the entire depth of the drill hole. Few of the drill logs indicate values per sample interval, which would allow the strip ratio (overburden to pay gravel) to be calculated; the dredge processed all of the gravel, so strip ratio calculations were unnecessary.

Bucket-line dredges are most effective on alluvial deposits (large volume and low, but predictable, grades). These characteristically represent relatively low-energy depositional environments and do not usually contain many boulders. If a bucket-line dredge were to be used on gulch-type placers, the boulder pavement would inflict great damage. Hard, rough bedrock was likewise difficult, and recoveries were poor.

Dredge piles are typically formed in arcs as the boat pivots back and forth around

an impact anchor called a "spud." The spud(s) was mounted near the back of the boat as either a single unit or a pair (figure 3.16) (Peele, 1941). Nuggets may be found in the oversize piles left by the stacker if they were larger than the screen size used on the dredge. However, in large, low-energy alluvial deposits, which are the most common feed source, oversize nuggets are unlikely. Values may remain on the bedrock surface, but if the washed, oversize piles are capped with angular bedrock, it is likely that the dredge adequately excavated enough bedrock so as to remove all of the resource.

Most of any remaining resource from this type of mining will be confined to unmined ground. Grades can be expected to be low. If the bedrock dipped below the reach of the bucket ladder, a good potential exists for remaining resources but at a high mining cost. Although a resource may remain, it is likely that the expense of stripping the pre-mined waste will render any potential profit nil. Remaining resources also exist where the dredge advanced, because a patch of gravels will have been skipped. Volumes typically are not great enough to justify re-mining/stripping and reclamation costs required to mine the remaining deposit.

Modern computerized dredges can easily process 40,000 $yd^3$ per day with a crew of three to five people. Ancillary crews are necessary to prepare the ground for the advance of the operation.

# Methods of Geophysical Evaluation

## Magnetometer

Geophysical methods have great potential as evaluation tools in some placer environments, but the limitations of each method must be understood. Literature research can provide the results of case studies, which can then be used in comparison with the geology of a particular placer deposit or prospect in order to determine the feasibility of applying a particular method. This is much cheaper than simply conducting a geophysical survey that is not suited to the situation. Geological surveys generally require specialized tools and expertise to acquire, process, and interpret the data, and the results must still be verified through confirmation testing and analysis. If the sampling program is adequate for the deposit, the additional economic burden of using geophysical tools may not add information worth the cost. However, on large alluvial deposits, if geophysical methods can narrow the target area the cost may be easily justified.

Numerous tools are available to estimate valley profiles and distance to bedrock. In some districts, proton magnetometers are used to map areas underlain by magnetite and ilmenite concentrations. Heavy mineral fractions, including gold, commonly exist at elevated grades in those concentrations. If the sampling program demonstrates a direct relationship between gold values and the magnetic anomalies, it may be possible to predict gold-bearing zones.

The survey is usually undertaken by establishing a surveyed grid (spacing of such grids is discussed in Chapter IV). After the readings at each station are recorded, the values are contoured like topographic map elevations. Higher readings indicate concentrations of magnetic minerals  for exploration. If the sample results reflect a close relationship between magnetic anomalies and placer gold, the entire mine plan may be designed around the results of the survey and the test holes. Use of magnetics will be limited in many areas because the magnetic signature of the bedrock may easily overwhelm those of placer deposits.

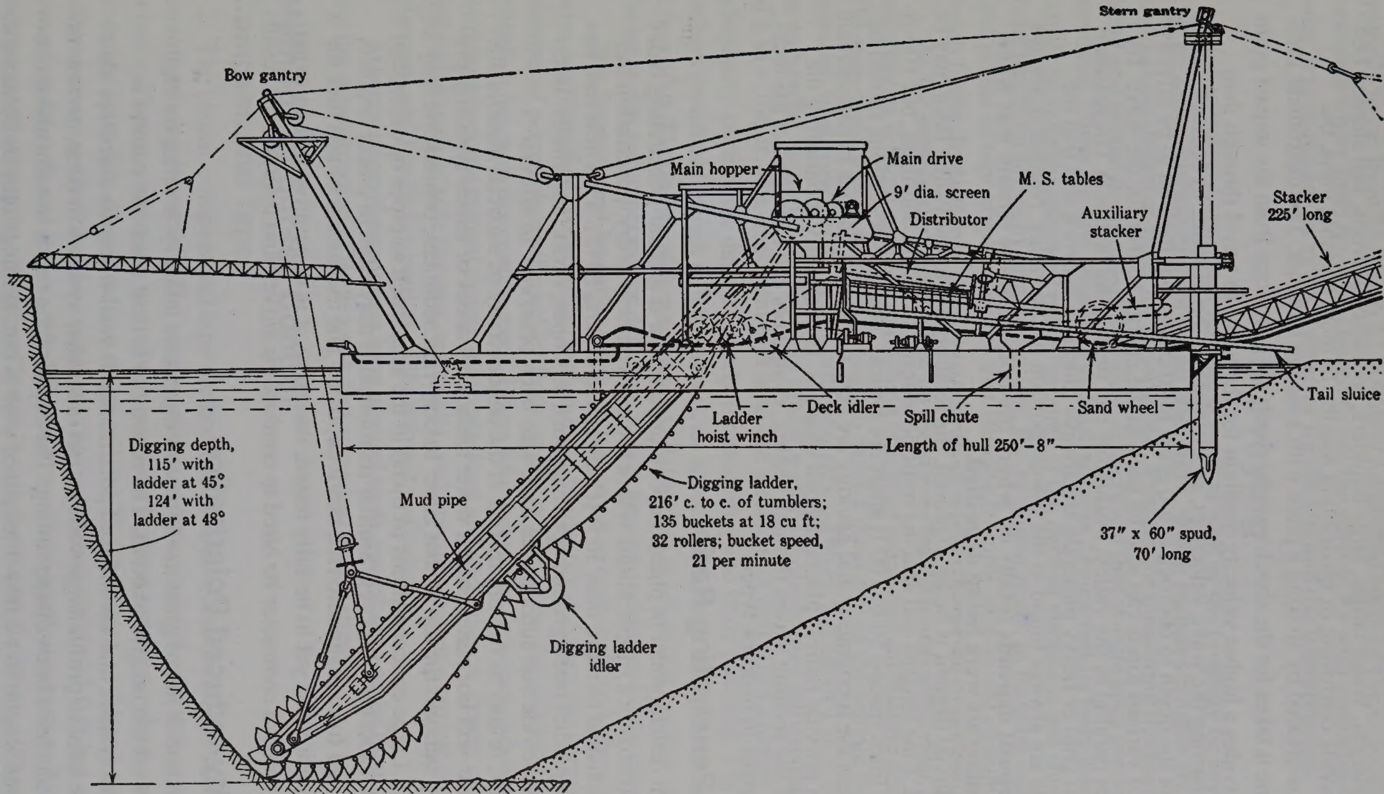


Figure 3.16. Side elevation of an 18-ft³ deep-digging gold dredge, equipped with tables, Yuba Manufacturing Company (Peele, 1941).

## Seismic (Refraction)

Seismic lines are typically designed to profile the depth to bedrock in valleys containing placers. Water tables, large boulders, sporadic outcrops, and sloping bedrock can provide confusing or misleading results. In most portable units, the shockwave is created by striking a plate with a sledge hammer. The instrument measures the time it takes for the shockwave to reach the geophone from the impact point. Bedrock provides a higher velocity medium for the wave to travel through than gravel; by charting the wave velocities, an estimate of the distance to bedrock can be made. Where the depth to bedrock is too great for the hammer method to be effective, explosives of various kinds can also be used as the energy source for the wave. By running lines parallel to the valley, evaluators can profile the bedrock. The assumptions are that gold or heavy minerals are always found on bedrock and that the paleostreams are always found in the lowest portion of the valley. Neither is always true. **The deposit depends totally on where the bottom of the stream was when the heavy minerals were being deposited.**

If a colluvial deposit is being explored, the relationship to the valley floor may be very limited. Line lengths and spacing must be tailored to local conditions, but 100-ft-long survey lines spaced 50 to 100 ft apart are typical. Numerous sections should be profiled unless the topography and geology are very uniform. Changes in paleostream gradient can provide radical placer deposit changes. By carefully monitoring the velocities of the seismic waves through testing, evaluators can also predict the locations of changes in bedrock types.

## Ground-Penetrating Radar

A recent development in placer deposit exploration is ground-penetrating radar. In open-pit (hard-rock) applications where the environment is dry, penetration has been accomplished to more than 30 ft (Daniels and others, 1992). This new tool has been used to predict underground openings such as stopes, drifts, and shafts. Interfaces between oxide and sulfide ores have also been observed. In alluvial environments, results have been mixed. If the conductivity of surficial materials is high, the radar will not penetrate the water table; clay zones or lenses typically prevent imaging beneath the top of that zone. In clay-rich sediment, penetration may be less than 3 ft. Large concentrations of metal in the area, such as pipes or cable, can also prevent a successful survey. Similar relationships may exist in placer deposits that are derived from magnetite-rich skarn deposits. The usefulness of this tool for placer exploration has yet to be fully tested; therefore, it is imperative that an experienced and qualified contractor be hired to conduct the survey and interpret the results.

## Resistivity-Induced Polarization

This method is not of great usefulness to the placer industry. It relies on high-voltage lines set out on grid patterns. The resistivity is read when the current is applied to the system, and the induced polarization is read when the current is shut off. It can be used to profile large valleys, but in smaller systems in deep, narrow valleys, the results have been disappointing. The depth of the test is usually about one-half of the line length. If a 1,000-ft length of wire is out, readings may be obtained to depths of 500 ft. It is, however, limited by conductivity problems created by porosity and clay, like many other geophysical systems.

Other than being used to profile bedrock, resistivity methods may show magnetite concentrations if they are large enough. Minimal costs for resistivity surveys typically range from $1,000 to $3,000/day. Additional costs can be expected in environments where lines must be cleared to run the survey. As with ground-penetrating radar, it is necessary to hire a contractor for the test and the interpretation.

# Surveying

It is extremely important that the deposit as well as the property be surveyed. This provides the base control for all later work, which includes boundaries, a map of the existing stream channel for reclamation, a datum for measuring thickness and gradient, and spatial locations of test sites. It is critical that sample sites are accurately surveyed. There are few situations as frustrating as having results from a sample that cannot be reliably relocated on the ground. If the deposit surface is not significantly disturbed from previous mining activity, the evaluator needs to be extra careful to note points of topographic change that indicate features such as old channels and bench limits. In disturbed areas, boundaries of worked areas are important.

As the sample sites are marked on the survey-based topographic map, the map becomes an integral part of establishing stripping ratios and calculating economics. The map scale should be large enough to exhibit the detail of the sample interval selected. In narrow gulch placers with complex geology, a scale of 1 in = 20 ft might be somewhat cluttered. A relatively uniform alluvial placer may only require a scale of 1 in = 100 ft. The important task is to use a scale that will allow enough detail to adequately portray the deposit clearly for modeling and mine planning. For mountain valleys (residual through gulch placers), an appropriate place to begin would be about 1 in = 50 ft. Flexibility with respect to available data is important because it is always easier to discard unnecessary data than it is to generate additional data afterward.

The deposit must be surveyed in such a way that both legal and physical boundaries are identified. Points of inflection must be identified during the survey. A number of points above the valley floor on either side of the deposit are important to establish the working environment. Edges of flood plains, benches, streams, and old workings become critical during mine planning and reclamation. Points of gradient inflection such as side streams, waterfalls, and outcrops become critical during the planning and feasibility portion of the deposit evaluation.

Modern mineral examiners have several tools available to assist them in surveying the deposit; some of these work and some just create stress.

## Methods of Survey Control

### Compass and Tape

The classic compass and tape method has always worked well for surveying remote mining properties. The single greatest error associated with this system occurs when evaluators are trying to maintain accurate vertical readings, which are typically accurate up to 3 ft. Angles have a range of 1° to 2°, dependent on the age and eyesight of the surveyor. Horizontal accuracy can be maintained within ±1.0 ft, but without the use of stadia rods and levels, it is difficult to maintain vertical accuracy. Calculated stripping ratios may be severely affected by a 1-ft error in elevation. If this method is the preferred choice, it is important to utilize tripods, steel tapes, and stadia rods whenever possible, rather than rely on hand levels or clinometers.

Because all data are placed on the map at the time of data collection, errors are usually discovered before too much damage occurs, and their effects can be minimized by adjusting the survey. In general, the technique lacks the precision necessary for detailed planning and feasibility analysis. It also tends to become less reliable in heavier vegetation and inclement weather, frequently due to frustration on the part of the crew.

## Plane Table and Alidade

The plane table and alidade are favorites of many senior engineers, and with the development of modern optics, the newer units are easier to use. Like the compass and tape method, the map is developed on site, so errors can be minimized, if not eliminated, in the field. The operation is somewhat labor-intensive, but with the use of stadia rods an experienced operator can prepare an accurate topographic map at low cost in a short time. Like compass and tape, the method is severely hampered by inclement weather and will not work well in heavy vegetation. The plane table system can produce many points that are independent of the others, such that an error is not always additive between points.

The products from either the compass and tape or the plane table and alidade systems are incompatible with today's computer systems and must be drafted separately by hand. To enter the final map into a computer, all the points must be scaled from a grid and digitized. The time and potential for errors involved would more than offset the initial time savings. Most universities have not taught plane table surveying for the past 5 to 10 years. The number of skilled operators is diminishing, as is available equipment.

## Total Station

The standard for the industry at this time is the total station, which comprises a theodolite, electronic distance measurer (EDM), and associated prisms. It represents a blend between a portable computer and an EDM. The complete system contains a data recorder that compiles the information into computer-ready format for analysis and drafting. Other than setup time, the numbers may be recorded nearly as fast as the rod is moved from place to place. Although mistakes cannot be realized until the drafting takes place, the system with the recorder eliminates human error and reduces the time needed to record the information. Accuracy is measured in thousandths of an inch, and distance shots are accurate to over 2 mi on clear days.

If the operator uses multiple tripods with prisms, much of the work can be accomplished by only one operator, although multiple rodmen increase the productivity. As long as visibility is good, weather has little effect on the operation. A crew of two can easily record 85 to 150 points in an 8-h shift in moderately heavy timber. Without the automatic recorder, the operator must take more time to record the data and prepare it for processing; this creates an opportunity for human error. In all cases, the better the operator's notes, the less chance of a serious error. Costs for leasing the equipment range around \$150/day with a purchase price of between \$10,000 and \$18,000/unit. It is vital to compare the finished map drafted in the office with the conditions in the field and make corrections as needed.

## Global Positioning Systems

Survey-grade global positioning systems (GPS) are clearly the future. The current handheld systems are too inaccurate to provide reliable numbers for *x–y–z* coordinate

locations. Most of the smaller handheld units are accurate to within 1 to 5 m horizontally, but vertical error may be three times that amount. Survey-grade systems may cost more than $50,000 for a three-unit system, where one is used as a base station and the others are used as rovers. The accuracy of a system of this kind can be ±0.05 cm.

The problem with most of these units and the system in general is the access, or lack thereof, to the necessary satellites for an accurate reading. In broad, flat, open areas at low latitudes, access appears to be nearly unlimited. However, in areas with dense trees, steep ridges, and narrow canyons, it can be nearly impossible to obtain sufficient access to enough satellites to achieve the necessary accuracy; these problems are aggravated even more at high latitudes. Actual cases in Montana show that it can take more than an hour per location to obtain adequate readings on some valley floors and that no satellite access may be available on steep north-facing ridges with heavy timber. In other cases, inability to access enough satellites has produced ±30-m accuracy with an instrument advertised with ±10-cm accuracy, despite a markedly increased reading time.

In the future when enough satellites are located over northern areas to provide consistent and dependable access, these systems may reduce by half the amount of personnel and time necessary for an accurate survey. Until then, they lack the dependability to justify the expense of time or money where conditions restrict satellite access.

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# Chapter IV: Sampling

# Sampling

## Introduction

The previous three chapters are designed to provide evaluators with tools to use in judging placer deposits. Many of these tools are used primarily either in instances where there is an absence of reliable sample data or as guides during sampling programs. Sampling is as critical as mapping in the evaluation of a deposit for economic development; both must be done well to produce a reliable result. The primary purpose of collecting representative samples is to accurately determine the mineral content or grade of a deposit. Data from sample sites provide information about the composition and character of the overburden, pay zone(s), and bedrock; indicate potential problems that could influence the economics of the deposit; and assist in the development of a realistic mining and reclamation plan. This chapter describes procedures used to gather and utilize data in a meaningful and dependable manner following the mapping that was described in Chapter III.

Placer deposits vary: in some the gold is distributed in homogeneous mixtures; in others it is concentrated in pockets, zones, or pay streaks. The chance of finding gold in a pan sample of an alluvial deposit derived from a sulfide source is good because it is relatively homogeneous; the chance of estimating the true value of that deposit from pan samples is considerably more difficult.

Deposits containing primarily medium to coarse gold particles from a gold skarn or low-sulfide quartz deposit are even more heterogeneous and most likely cannot be accurately evaluated with pan samples. Some deposits of this type have demonstrated no values even after more than 300 consecutive pan samples were taken from a site. However, bulk samples of more than 5 $yd^3$ processed from the same site will probably produce a consistent value.

In heterogeneous deposits, the grade may be valued at hundreds of dollars per cubic yard in the highest grade zones and a few cents per yard elsewhere. Many placer deposits will have one or more of these high-grade pay channels or zones. In a valley 300 to 500 ft wide, the high-grade pay channel may be only 30 to 70 ft wide, with a distinct drop in the values outside this channel. Information from experienced mine operators indicates that the boundary between pay and waste rock is often abrupt, without gradational change. The "nugget effect," which arises from the high value of a single large gold particle, is a well-known problem in sampling gold deposits. Sampling procedures must be designed to account for this and other problems to ensure an accurate and cost-effective economic assessment of a property.

## Vertical Sample Intervals

Each step in the evaluation process is a balance between cost and accuracy. Ideally, the evaluator should be able to delineate the pay zone with a high degree of confidence. However, even if this happens, it may be difficult, if not impossible, to mine to that precision because of equipment limitations, operator capabilities, or abrupt changes in the vertical position or character of the pay zone.

To minimize cost and prevent dilution, the vertical sample interval should be no greater than 2 to 3 ft. Visually identifiable changes in depositional characteristics such as color, particle size, rock type, degree of angularity, texture, degree of sorting, or

many other characteristics can often be identified and traced throughout the deposit. Sample breaks should be made at these horizons; these visual indicators that allow the machinery operator to more readily identify the vertical extent of the pay zone during subsequent mining are very important.

Dilution of values by sampling a vertical interval that is too large can distort or bias the economic evaluation of a property. For example, on a U.S. Bureau of Mines project, one evaluator sampled 20 vertical ft of material in one sample that indicated a value of $3.12/bcy at $300/troy oz of gold. However, additional sampling indicated that only the top 5 ft contained gold. The correct value for just the 5 ft of gold-bearing material was $12.49/bcy. For that property, the incorrect (lower) value was near the break-even point, while the correct value ranked the property as quite profitable.

Some excavations will stand without collapse for decades; others may stand for only minutes or even seconds before collapsing. An excavation of greater than 3 ft in depth and less than 3 ft in width will require some form of shoring before it is safe to enter. Many deposits are wet, and rapidly caving ground is common. Visual indicators are typically difficult to recognize under these conditions. There is often no time available to lay out a tape and get an accurate measurement of a sample interval. The evaluator may be limited to using bucket sizes of the sampling equipment as a reference to estimate the vertical interval of a sample. A 1-yd$^3$ excavator bucket, commonly used for bulk sampling, is approximately 3 ft long (base of the teeth to back of the bucket). A 2½-yd$^3$ dragline bucket is approximately 3 ft high.

It is vitally important to record all field observations during sampling and keep this information for future reference. The notes should include at least the following items from each location examined during reconnaissance and at each sample site:

1. The date
2. Names of people present
3. Location on the property
4. Geologic unit
5. Rock types and minerals present
6. Sediment types, distribution, and content of organic matter
7. Thickness of horizons and distinguishing features
8. Overburden thickness
9. Estimated ground-water and surface-water volumes
10. Geologic structure of outcrops and bedrock, including faults, folds, etc.
11. Reference to roll and frame number if photographs are made at the site
12. Description of sample(s) collected, including dimensions, weight, boulder factor, swell factor, etc.
13. Description of gold observed
14. Description of mine and prospect workings, if any

Appendix F contains an information checklist originally developed by John Wells (1969) and considered an industry standard for decades. The list has been updated and serves as a good way to ensure that representative data are systematically recorded.

It is often tempting to write "same as before" in place of recording detailed notes, which is especially true in areas that appear to be uninteresting. **That tendency must be avoided**. The gradual changes across a deposit will eventually become important. It is often difficult or impossible to return for a later visit, especially if access is poor or if the exposure has been obliterated or backfilled.

Pictures will help explain your observations but, by themselves, are not adequate substitutes for good notes. Pictures with accompanying sketches, particularly when supplemented by precise measurements, are very useful and tend to force the evaluator to examine the exposure more critically.

As shown in figure 4.1, sample intervals that accurately represent the stratigraphic column, thickness intervals, and materials can be selected. Descriptions and comments that will greatly assist the evaluation at a later date should accompany the samples. A well-marked tape dropped over the pit edge will allow the evaluator to safely determine the thickness of gravel units in unsupported pits too dangerous to enter even if they are not rapidly caving. If the top of each hole is surveyed for location and elevation, the pay zones between holes can be accurately determined. Defining the boundary between pay gravel and waste is critical to the economics of the deposit. The process of defining the waste is as important as that of establishing the pay values. Every cubic yard of waste processed during mining will cost $1 to $2 more than if it had been stripped and stacked; this increases the overall operating costs and also decreases the effective life of the equipment and settling pond.

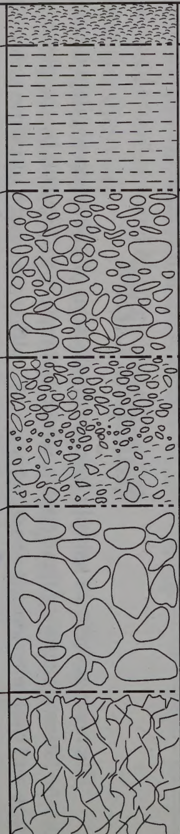
Each sample pit should include a separate sample of bedrock, if reached. Typically, the valuable minerals in the deposit will not extend below the point in bedrock that can be penetrated by an excavator. A possible exception to this norm would be a residual placer overlying a highly altered lode. In that case, the values may decrease but not stop in the bedrock. Hydrothermal alteration may allow mining to continue for hundreds of feet into the bedrock without the need for blasting. If bedrock is soft but has no values, care must be taken to stop digging when the values go away.

The notes and records taken during sampling will impact the evaluation. Every hypothesis should be noted and each measurement recorded; **memory cannot duplicate accurate field notes**. Often, extended periods of time may lapse between the field activities and interpretations drawn from the notes. Good notes may spell the difference between competent and incompetent testimony in the case of litigation. A property owner will probably suffer economic consequences from sloppy notes; professionals such as consultants or government evaluators may suffer legal consequences.

## Sample Lines

The arrangement of sample lines and selection of site intervals depends largely on the heterogeneity of the deposit, which is strongly influenced by the placer deposit type and the lode deposit characteristics. A sulfide-sourced (ultrafine gold) alluvial placer deposit that has undergone long-distance transport may be so predictable that the sample lines may be thousands of feet apart and still yield accurate predictions of gold values. In contrast, a gulch placer with coarse gold may not yield accurate predictions in 50-ft intervals. The dependability and predictability of the deposit must be determined on a deposit-by-deposit basis. Changes to a sampling program as a deposit is better understood are common.

A detailed characterization of the deposit is undertaken by excavations along lines that dissect the deposit into resource blocks. There is no single correct answer to the question of how to determine the best intervals between holes along the line or the distance between lines. Because there are similarities between deposits of the same type, the reference information shown in table 4.1 provides a beginning point. As the results of the sampling become available, the lines and site spacing of hole locations may



| Photo of Section | Distance (ft) | Value $yd³ | Description | Comments |
|---|---|---|---|---|
| | 1.1 | -0- | Soil, roots, sandy-silt, tan, 2% volcanic ash | Unconsolidated; easy to strip |
| | 3.0 | $0.03 | Well-sorted, 70% rounded shale pebbles; 10% sand; 20% clay, gray-tan; small clay lens, dry <u>Sample UA-1</u> | Firm, stands well, dribbles, 21% swell; 2% dilution |
| | 3.1 | $0.28 | Well-sorted, and consolidated; 15% boulders 1-3' x 10" x 8"; 60% cobbles subangular-to-subrounded; (quartzite 20%; argilite 70%; intrusive 10%) 10% silt & clay; 10% sand; 5% pebbles, tan-orange; appears to be a cobble lens <u>Sample UA-2</u> | Consolidated; hard to dig; 31% swell; 10% dilution; dry |
| | 3.2 | $0.05 | Well-sorted, medium consolidation; 80% cobble; 5% clay; 15% sand; particles subrounded-to-subangular; 75% argilite (tan); 25% quartzite (gray) <u>Sample UA-3</u> | Consolidated; medium digging; stands well, dry; 33% swell; 12% dilution |
| | 2.8 | $10.52 | 65% boulder, unsorted; manganese stains potentially coating gold; 15% cobble; 5% pebble: 10% sand; 5% clay; 55% intrusive (granodiorite); 21% argillite; 24% quartzite zone: orange-black; clay sticky but not hydrophobic <u>Sample UA-4</u> | Consolidated; medium digging; stands well, 42% swell; 10% dilution |
| *no picture* | 1.5 | $28.04 | Friable orange-black shale; some quartz veining; heavily altered; large fractures <u>Sample UA-5</u> | 28% swell; tight @ 18"; tough |

Figure 4.1. Example of a placer stratigraphic column.

Table 4.1 Proposed maximum placer sample site distances for a deposit characterization analysis

| Deposit type | Distance between lines (ft) | Distance between holes (ft) |
|---|---|---|
| Residual | 50 | 25 |
| Colluvial/ eluvial | 100 | 50 |
| Debris flow | 200 | 50 |
| Desert | 50 | 50 |
| Alluvial fan | 50 | 50 |
| Gulch | 250 | 50 |
| Eolian | 50 | 25 |
| Stream or river/ alluvial | 750 | 250 |
| Flood gold | 750 | 250 |
| Beach | 750 | 250 |

need to be adjusted, depending on the deposit continuity between samples. Sampling of vertical intervals already proven to be barren is a waste of time and money, as are sample sites beyond any identified pay zone boundaries. Erratic values discovered early in the program may force the evaluator to reduce the sample site spacing, which will minimize the variance of the sample values but increase the number of holes and cost. At some point in the project, the evaluator should recognize the minimum level of sampling necessary to reliably evaluate the property. This early portion of the program is called *indexing* the property.

Each deposit type on the property must be sampled independently by its own evaluation criteria and indexed to be accurately evaluated at the optimum level of expenditure; exceeding that level would be money needlessly spent, while spending less could result in unnecessary risk and possible failure.

During patent and validity examinations, government professionals will probably not utilize the same density of samples as a company preparing for a feasibility analysis. The government's job is to verify industry results. Consequently, their work is a sample of the industry program. However, government evaluators need to understand the necessary components of the industry's sampling program to understand the significance of the government's sampling results.

## Sample Size

Much has been written about the need to obtain samples of adequate size, but most of this information has been based on statistical derivations or assumptions that are generally suitable only to specific types of lode gold deposits. As an example, USGS Professional Paper 625-C (Clifton and others, 1969) has some applicability to lode or geochemical samples but is inadequate for placer. The basic assumptions made in this paper are that, "the gold particle mass is uniform…the gold particles are randomly distributed through the deposit being sampled," and "the weight of the sample is expected to contain 20 (gold) particles." This rarely occurs in placer deposits, except in a few alluvial or sulfide-sourced deposits; consequently, this often-quoted paper has little, if any, general application to sampling placer deposits.

A more recent publication (Pitard, 1989) provides an analysis of a fine-gold alluvial placer that was core-drilled and shows a variance of ±32 percent. Unless all of the samples were of greater value than the operational costs, a 32 percent margin of error would not inspire much confidence in the evaluation. Although this example may have some applicability because of the relatively uniform distribution of fine gold in a transport-type deposit, it is unlikely that any of the "lag" deposits would provide acceptable results with the application of geostatistical methods. The use of small-

diameter drill sampling for placers has long been known to result in high degrees of uncertainty and unreliable results (Wells, 1969).

## Standard Size Calculation Method

To obtain useful results, the samples must be large enough to be representative of the most influential element of the analysis. In gold placers, as with many high-value substances such as gemstones or platinum-group metals, the dominant particle weight (cumulative weights within a particle weight range that has the most influence on the value of the sample) controls the results. Particles in that weight range have a nugget effect that renders many of the other weight range particles uninfluential.

To minimize the influence of the nugget effect, the particle weight distribution of the gold in the deposit must be determined. Placers do not have a homogeneous distribution of precious metals at all sample sizes. Sample results become more consistent for certain particle weight ranges as the sample volume increases. Where different deposit types overlie each other, the larger of the two weight ranges must be chosen. However, each deposit must be evaluated for the correct sample size.

As shown in figure 4.2, larger sample sizes have a better probability of intercepting the larger (heavier), but less common, particles upon which the economics of the deposit may depend. If the weight of one large particle is 10 times that of the sum of all of the smaller particles and if the sum of the smaller particles does not exceed the cut-off value, then the smaller particle weight ranges have minimal influence. Only the larger weight ranges may be important in the evaluation of some deposits. To quantitatively determine the weight distribution of the gold particles in a deposit, an evaluator should collect a sample of 5 $yd^3$ or larger from the main pay area or a known production zone within the deposit. The recovered gold will likely provide a weight

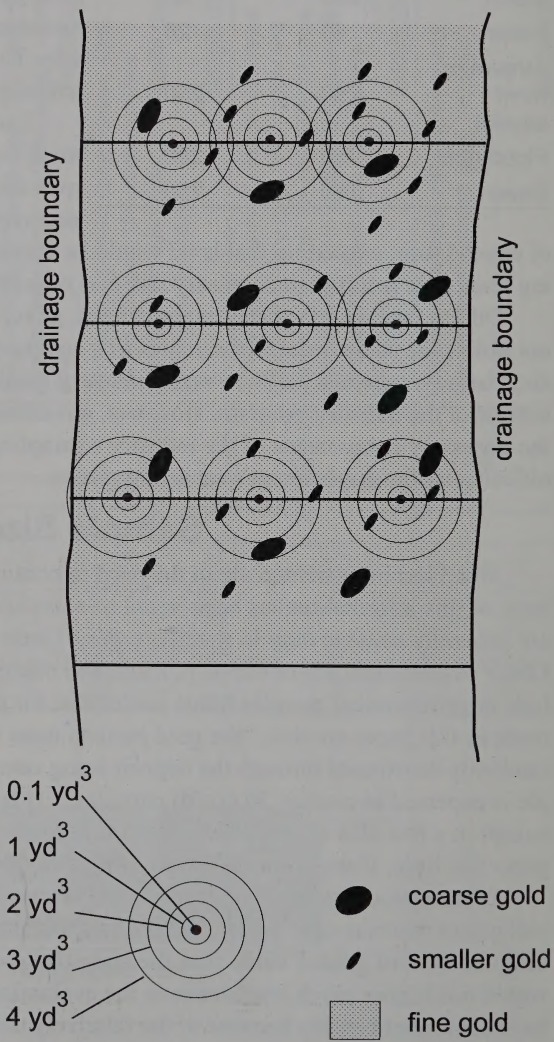



Figure 4.2. Idealized gold particle interception by sample size.

Table 4.2 Sauerkraute Creek gold particle weight distribution in a 3-yd$^3$ sample

| Gold particle weight | Cumulative weight per range (g) | Percentage total | Cumulative percentage | Cumulative weight by sample size (g) | Cumulative value per sample |
|---|---|---|---|---|---|
| 0.00002 | | | | 0.00002 | 0.0004 |
| 0.00004 | | | | 0.00006 | 0.0003375 |
| 0.00005 | | | | 0.00011 | 0.0001875 |
| 0.00006 | | | | 0.00017 | 0.0004125 |
| 0.00006 | | | | 0.00023 | 0.0006375 |
| 0.00009 | | | | 0.00032 | 0.000975 |
| 0.00022 | | | | 0.00054 | 0.0018 |
| 0.00022 | | | | 0.00076 | 0.002625 |
| 0.00023 | | | | 0.00099 | 0.0034875 |
| 0.00026 | | | | 0.00125 | 0.0044625 |
| 0.0003 | | | | 0.00155 | 0.0055875 |
| 0.00031 | | | | 0.00186 | 0.00675 |
| 0.00033 | | | | 0.00219 | 0.0079875 |
| 0.00033 | | | | 0.00252 | 0.009225 |
| 0.00042 | | | | 0.00294 | 0.0108 |
| 0.00046 | | | | 0.0034 | 0.012525 |
| 0.00056 | | | | 0.00396 | 0.014625 |
| 0.00056 | | | | 0.00452 | 0.016725 |
| 0.00058 | | | | 0.0051 | 0.0189 |
| 0.00064 | | | | 0.00574 | 0.0213 |
| 0.00067 | | | | 0.00641 | 0.0238125 |
| 0.00069 | | | | 0.0071 | 0.0264 |
| 0.00078 | | | | 0.00788 | 0.029325 |
| 0.00079 | | | | 0.00867 | 0.0322875 |
| 0.00081 | | | | 0.00948 | 0.035325 |
| 0.00082 | | | | 0.0103 | 0.0384 |
| 0.00096 | | | | 0.01126 | 0.042 |
| 0.00098 | | | | 0.01224 | 0.045675 |
| 0.00119 | | | | 0.01343 | 0.0501375 |
| 0.00137 | | | | 0.0148 | 0.055275 |
| 0.00142 | | | | 0.01622 | 0.0606 |
| 0.00145 | | | | 0.01767 | 0.0660375 |
| 0.00148 | | | | 0.01915 | 0.0715875 |
| 0.00158 | | | | 0.02073 | 0.0775125 |
| 0.00166 | | | | 0.02239 | 0.0837375 |
| 0.00169 | | | | 0.02408 | 0.090075 |
| 0.0018 | 0.02588 | 0.12827496442 | 0.12828 | 0.02588 | 0.096825 |
| 0.00208 | | | | 0.02796 | 0.104626 |
| 0.00248 | | | | 0.03044 | 0.113925 |
| 0.00273 | | | | 0.03317 | 0.1241625 |
| 0.0029 | | | | 0.03607 | 0.1350375 |
| 0.00297 | 0.01316 | 0.06522791854 | 0.1935 | 0.03904 | 0.146175 |
| 0.00327 | | | | 0.04231 | 0.1584375 |
| 0.0034 | | | | 0.04571 | 0.1711875 |
| 0.0037 | | | | 0.04941 | 0.1850625 |
| 0.00371 | 0.01408 | 0.069787925 | 0.26329 | 0.05312 | 0.198975 |
| 0.00448 | 0.00448 | 0.02220524886 | 0.2855 | 0.0576 | 0.215775 |
| 0.01041 | | | | 0.06801 | 0.2548125 |
| 0.018 | | | | 0.08601 | 0.3223125 |
| 0.0189 | | | | 0.10491 | 0.3931875 |
| 0.0195 | 0.06681 | 0.33114568675 | 0.61664 | 0.12441 | 0.4663125 |
| 0.0255 | | | | 0.14991 | 0.5619375 |
| 0.027 | 0.0525 | 0.26021776013 | 0.87686 | 0.17691 | 0.6631875 |
| 0.0317 | | | | 0.20861 | 0.7820625 |
| 0.0346 | 0.0663 | 0.32861785708 | 1.20548 | 0.24321 | 0.9118125 |
| 0.0614 | | | | 0.30461 | 1.1420625 |
| 0.0659 | 0.1273 | 0.63096611172 | 1.83644347252 | 0.37051 | 1.3891875 |
| 0.074 | 0.074 | 0.36678312857 | 2.2032266011 | 0.44451 | 1.6666875 |
| 0.1939 | 0.1939 | 0.96107092743 | 3.16429752853 | 0.63841 | 2.3938125 |
| 0.321 | | | 3.16429752853 | 0.95941 | 3.5975625 |
| 0.361 | 0.682 | 3.38035261737 | 6.5446501459 | 1.32041 | 4.9513125 |
| 0.4389 | | | 6.5446501459 | 1.75931 | 6.5971875 |
| 0.4642 | | | 6.5446501459 | 2.22351 | 8.3379375 |
| 0.473 | 1.3761 | 6.82067923279 | 13.3653293787 | 2.69651 | 10.1116875 |
| 0.5626 | | | 13.3653293787 | 3.25911 | 12.2214375 |
| 0.5767 | 1.1393 | 5.64697322136 | 19.0123026 | 3.83581 | 14.3840625 |
| 0.6678 | 0.6678 | 3.30996990891 | 22.322272509 | 4.50361 | 16.8883125 |
| 0.9965 | 0.9965 | 4.9391809138 | 27.2614534228 | 5.50011 | 20.6251875 |
| 1.2355 | 1.2355 | 6.1237912885 | 33.3852447113 | 6.73561 | 25.2583125 |
| 2.6058 | | | 33.3852447113 | 9.34141 | 35.0300625 |
| 2.8356 | 5.4414 | 26.97045561899 | 60.3557003303 | 12.17701 | 45.6635625 |
| 3.6298 | 3.6298 | 17.99120810928 | 78.3469084395 | 15.80681 | 59.2753125 |
| 4.3686 | 4.3686 | 21.65309156047 | 100 | 20.17541 | 75.6575625 |
| TOTAL | 20.17541 | 100 | 200 | | |

range distribution of gold particles within the deposit. After the critical weight range is identified, smaller weight ranges will be effectively sampled automatically.

After the gold is recovered, each gold particle is weighed and the results are recorded in a computer spreadsheet where the data can be sorted in ascending values and divided into various weight range categories. An example of this is the analysis of the Sauerkraute Creek deposit near Lincoln, Montana (table 4.2). The individual values in each weight range (orders of magnitude as shown in table 4.2) are first totaled, then divided by the total weight of all the particles, and then multiplied by 100 to develop the cumulative weight–percentage distribution. As shown in table 4.2 (far right column), the cumulative sum of the values of gold particles is also an important tool. In this example the sum of the values of the 49 smallest particles is only a few cents; consequently, if extra costs are incurred to design and construct a plant capable of recovering those small particles, the investor may not ever recoup the additional cost of construction. The table shows that for this deposit, the larger particles dominate the weight and, therefore, the economic value of the gold to be recovered. Thus a simple sluice or jig recovery system may be the most effective concentration method.

By graphing the percentage of each weight range in the spreadsheet (*y* axis) against the weight range categories (*x* axis), the predominant influencing weight range can be determined from the graph (figure 4.3). This should indicate which gold weight range has the greatest influence on the value of the deposit and, therefore, represents the weight range to be used in the determination of the sample size in the next step. If two or more ranges have significant influence, the evaluator should choose the larger of the two since the accuracy of that sample will be most affected by the larger size. In figure 4.3, the most influential particle weight range is >2 and <3 g. This weight range must be used to appraise the deposit and avoid the nugget effect. It may be possible to choose a smaller size to evaluate the minimum economics and decrease the exploration costs.

The next step entails the use of the nugget effect graphs (figures 4.4 through 4.7) in the determination of the correct sample size. These graphs compare the values of

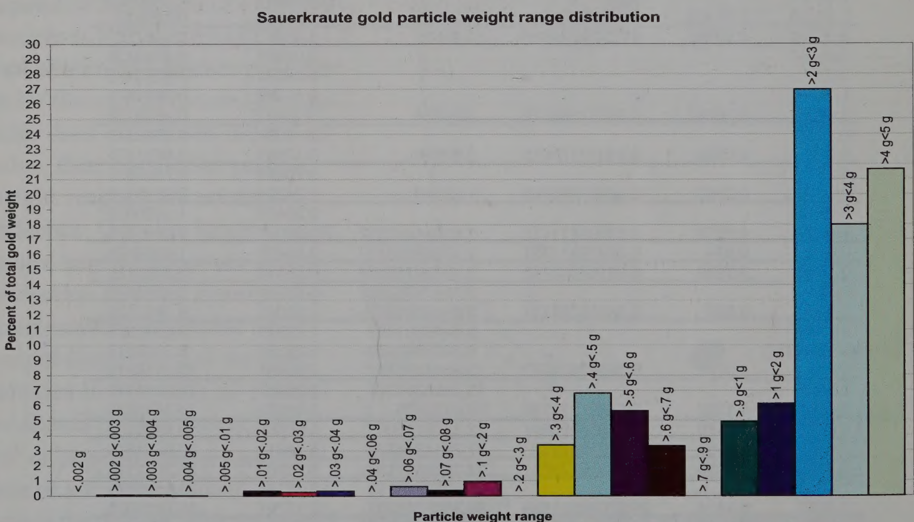



Figure 4.3. Distribution of gold weight by weight range in the Sauerkraute Creek deposit.

gold particle weights from 0.001 to 32 g at $350/troy oz and portray how these values would influence samples ranging in size from 0.005 to 300 $yd^3$ (appendix G). The values were plotted on the *y* axis and the sample sizes were plotted on the *x* axis for each particle weight. The graphs show that as the sample size increases, the influence of each particle weight range diminishes. Any sample size to the right of the point of inflection for each particle weight range is minimally influenced by the nugget effect. An adequate sample size can be chosen from the graph where the curve parallels the *x* axis. That size will minimize the sampling cost while meeting the needs of the type of evaluation chosen.

The costs associated with collecting larger samples are greater, but larger samples provide more accurate data and grade consistency. The choice is a function of cost relative to the need for accuracy. The evaluator must decide, given the price of sampling, how much accuracy can be forfeited without damaging the evaluation of the property.

Because of the high cost of sampling, especially with very large bulk samples, a second test may be applied to reduce the sample size. This test may be used to determine the minimum economics necessary to show a profit, but not the anticipated profit potential of the deposit. When the cumulative value (shown in table 4.2) exceeds the calculated break-even point (cutoff grade), the examiner can read the critical particle weight range from the left column. The cumulative sample value at the cutoff grade is calculated as follows:

$$\frac{\text{(cumulative gold weight [g]) x (\$/troy oz/31.103 g/troy oz)}}{\text{sample size (yd}^3\text{)}} = \$/\text{yd}^3.$$

As shown in table 4.2, if the break-even point or cutoff grade is calculated at $4.50/$yd^3$, then the particle range that is >0.4 and <0.5 g is determined to be the minimal influencing particle weight range. Figure 4.5 shows that a 1-$yd^3$ sample/3 vertical ft may be acceptable to test for the profitability of this property. The most influential particle size, as shown in figure 4.3, would still be in the range of >2 and < 3 g. That weight range requires the use of figure 4.6, which shows that the correct sample should be no smaller than 20 $yd^3$, while a 50-$yd^3$ sample would probably produce the best results.

## Alternative Method for Calculating Sample Sizes

Situations will occur in which equipment is unavailable for the large samples necessary to index the deposit. Under these circumstances, the evaluator can use data gathered during the evaluation process to determine a reasonable sample size. Although not as accurate, this alternative system considers many pieces of critical data and results.

The procedure considers the following:

1. Gold particle weight distribution of historic production
2. Historic mining methods
3. Gold fineness
4. Common accessory minerals
5. Predominant gold characteristics
6. Lode source deposit types

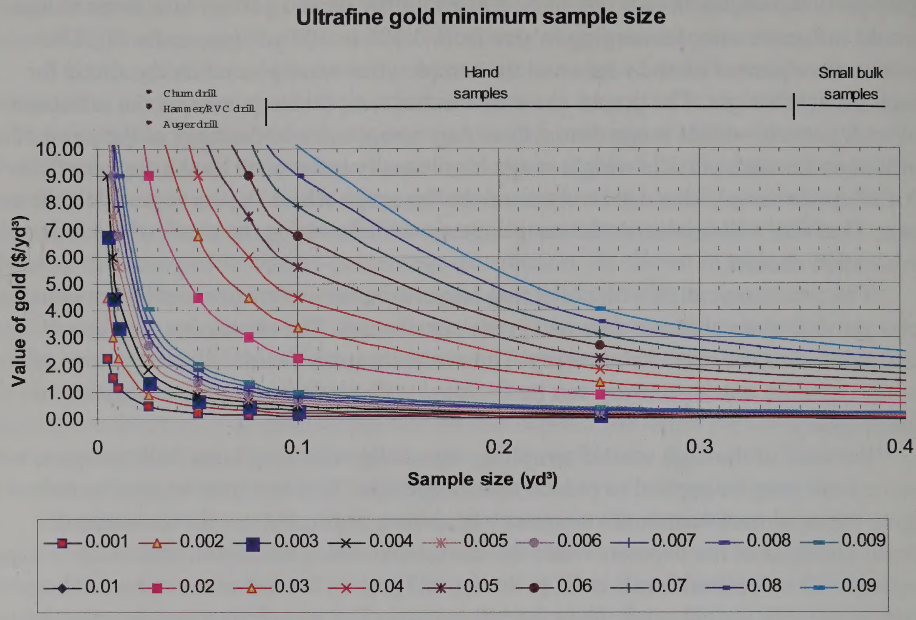



Figure 4.4. The influence of ultrafine particle size in placer gold deposits. Data are derived from appendix G, and assume that a single gold particle is present in each sample (gold @ $350/troy oz).

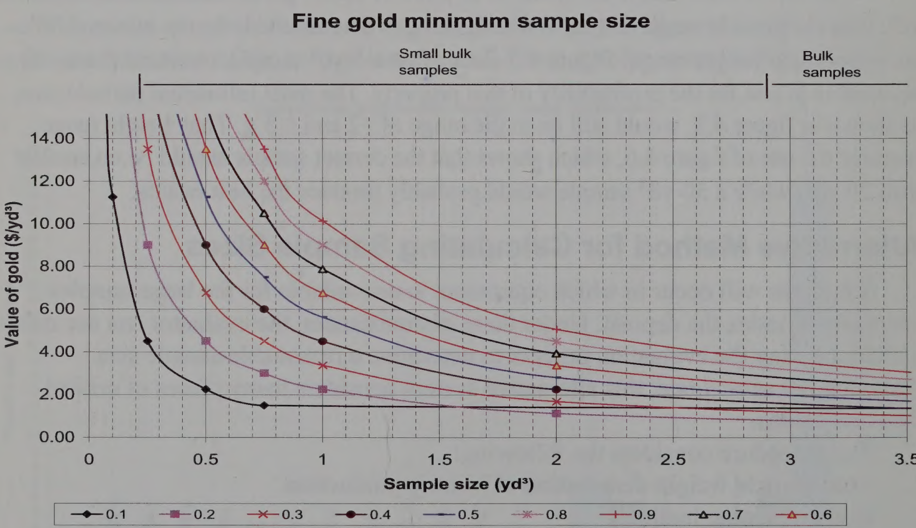



Figure 4.5. The influence of fine particle size in placer gold deposits. Data are derived from appendix G, and assume that a single gold particle is present in each sample (gold @ $350/troy oz).

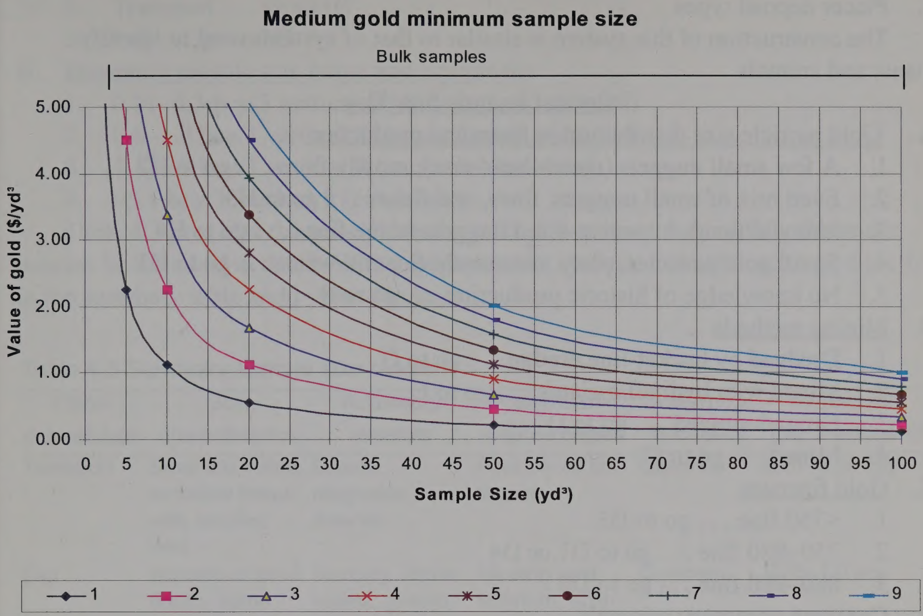



Figure 4.6. The influence of medium particle size in placer gold deposits. Data are derived from appendix G, and assume that a single gold particle is present in each sample (gold @ $350/troy oz).

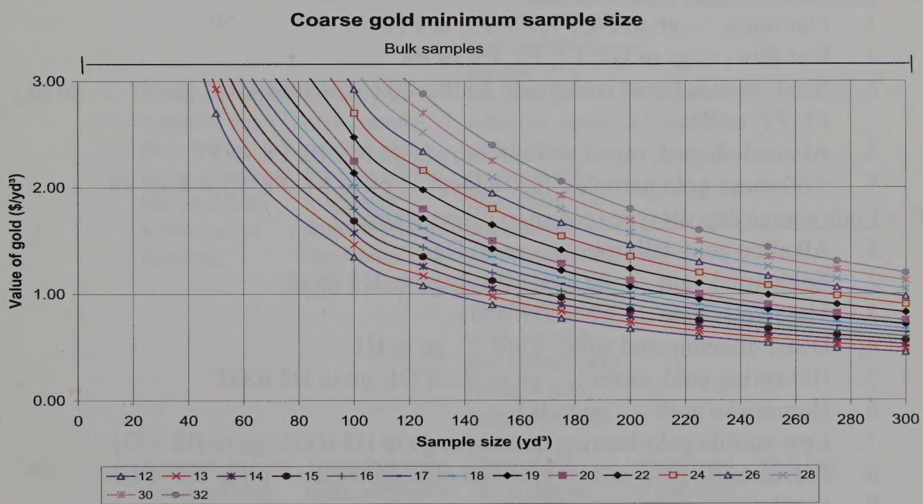



Figure 4.7. The influence of coarse particle size in placer gold deposits. Data are derived from appendix G, and assume that a single gold particle is present in each sample (gold @ $350/troy oz).

7. Placer deposit types

The construction of this system is similar to that of systems used to identify plants and animals.

Critical Sample Size Key

A. Gold particle size distribution in historical production
   1. A few small nuggets (match-head size), mostly fines . . . go to H2
   2. Even mix of small nuggets, fines, and flakes . . . go to H3
   3. Many almond- to peanut-sized nuggets, some fines . . . go to H4
   4. Small gold particles, platy, commonly float on water . . . go to H1
   5. No knowledge of historic production . . . go to B

B. Mining methods
   1. Dredged by bucket-line dredge . . . go to D
   2. Mined with hydraulic giants . . . go to E
   3. Ground-sluiced . . . go to D
   4. Mined . . . go to C

C. Gold fineness
   1. <750 fine . . . go to D3
   2. 750–880 fine . . . go to D1 or D4
   3. 880–980 fine . . . go to D2

D. Common accessory minerals
   1. Mercury and/or abundant zircons . . . go to E1 or F2
   2. Magnetite–ilmenite and/or tungsten minerals, garnets . . . go to E4; if E4 is not present go to F10
   3. Cassiterite and/or sulfides . . . go to E5; if E5 is not present go to F9
   4. Quartz . . . go to E1 or E3
   5. If none of the above, go to E

E. Gold predominant characteristics
   1. Flat-thick . . . go to F6, F7, F8, F9, or F10
   2. Flat-thin . . . go to G1, F1, F2, F3, or F4
   3. Gold crystals (most commonly feather-like structures) and quartz . . . go to F5, F7, or F8
   4. Almond-shaped, round and smooth . . . go to F10, F8, or F7
   5. < 60-mesh gold particles, lacy edges . . . go to F1, F2, F3, F4, or F5

F. Lode source deposit type (common placer sources)
   1. Alkaline gold–tellurium . . . go to H1
   2. Epithermal vein . . . go to H1 if G1; go to H2 if G2
   3. Massive-sulfide . . . go to H1 if G1
   4. Distal disseminated silver–gold . . . go to H1
   5. Hot spring gold–silver . . . go to H1 if G1; go to H2 if G2
   6. Homestake gold . . . go to H2
   7. Low-sulfide gold-bearing quartz . . . go to H3 if G2; go to H2 if G1
   8. Polymetallic gold–silver; vein and disseminated . . . go to H2 or H3
   9. Porphyry–copper . . . go to H2
   10. Skarn gold; polymetallic veins, porphyry-related . . . go to H2 if G1; go to H4 if G2
   11. Skarn copper . . . go to H3 if G1; go to H4 if G2

G. Placer deposit type

   1. Transport . . . go to H1
   2. Lag . . . go to H3

H. Minimum sample size range and equipment
   1. 0.01–0.5 bcy/3 vertical ft (drills or hand channel)
   2. 0.6–1.0 bcy/3 vertical ft (hand channel and bulk)
   3. 1.1–5.0 bcy/3 vertical ft (excavator/backhoe)
   4. >5.1 bcy/3 vertical ft (excavator)

Table 4.3 provides the consolidated results. It is critical that initially the entire process be followed in detail. With experience, the evaluator can choose to go directly to the summary table and bypass the key.

Table 4.3 Summary sample size range

| Placer deposit type | Gold characteristics | Accessory minerals | Possible lode deposit origins | Occurrence frequency | Sample size (per 3 vertical ft) |
|---|---|---|---|---|---|
| Transport | Small flat, rolled, or folded flakes with leached rims | Quartz, magnetite, ilmenite | Possibly all but skarns | Common | 0.01–0.05 bcy |
| Lag | Numerous small flakes, some lacy edges, few nuggets, 3-D particles (having thickness to go with length and width) | Mercury, zircon, quartz, galena, pyrite, tin, rare earths, magnetite, ilmenite, hematite, barite, copper, chalcopyrite, monzonite, xenotime, columbite, apatite, garnets | Alkaline gold–tellurium, epithermal gold, massive-sulfide, distal disseminated silver–gold; hot springs gold–silver; Homestake gold; low-sulfide quartz; poly-metallic gold; porphyry–copper | Common | 0.06–1.0 bcy |
| Lag | Mixture of small nuggets, flat-thick flakes, some gold crystals possible; some quartz attached | Mercury, zircons, quartz, galena, pyrite, tin, rare earths, magnetite, ilmenite, hematite, barite, copper, chalcopyrite | Alkaline gold–tellurium, epithermal gold, massive-sulfide, distal disseminated silver–gold; hot spring gold–silver; Homestake gold; low-sulfide quartz; polymetallic gold; porphyry–copper | <30 percent of deposits | 1.1–5.0 bcy |
| Lag | Almond- to peanut-sized nuggets, gold crystals possible, quartz attached | Tungstate minerals, magnetite; ilmenite; hematite, chalcopyrite, monzonite, xenotime, columbite, apatite, garnets | Skarn gold; skarn copper; polymetallic gold; low-sulfide gold quartz | <5 percent of deposits | >5.0 bcy |

## Sampling Methods

The choice of tools for use in the sampling of a placer deposit is dictated by the sample size, which is determined by the predominant weight range of the gold particles in the deposit. The influencing weight range distribution of the particles is controlled by the lode source deposit type and the depositional environment or placer deposit type (table 4.4). A portion of the ultrafine particle (<0.01 g) deposits can be successfully drilled with the use of various drills shown in table 4.5. These deposits most commonly contain ultrafine particle sizes in stream-river/alluvial, flood, and beach deposits, where the fine fraction of gold particles is removed from the source area and redistributed some distance away in a lower energy environment. Drills may also be used on the lag-type deposits where the lode source predominantly produces very small particles of disseminated gold throughout the deposit, such as an oxidized sulfide deposit.

In earlier sections, the relationship between predominant gold particle weight and sample size was established; the larger the predominant gold particle size in the deposit, the larger the sample should be. Samples may range in volume from one-tenth of an lcy to hundreds of lcy. Consequently, the smaller samples may be collected with drills, while the larger bulk samples must be collected with essentially the same types of equipment that would be used to mine the deposit.

Table 4.4 Sampling methods available

| Placer deposit type | Lode source type | Minimum excavation methods and equipment[1] |
|---|---|---|
| <u>Lag deposits</u><br>Residual; colluvial debris flow, desert, alluvial fan, gulch, eolian | <u>Ultrafine gold systems</u>[1] Alkaline gold–tellurium, massive-sulfide, chromite–PGM, Carlin-type, epithermal, disseminated Homestake, low-sulfide quartz, overlook | Drills |
| <u>Transport deposits</u><br>Stream/river/alluvial, flood, beach | Polymetallic replacement, porphyry–copper, and porphyry–molybdenum | Drills |
| <u>Lag deposits</u><br>Residual; colluvial/eluvial debris flow, desert, alluvial fan, gulch, eolian | <u>Fine–coarse gold systems</u>[1]<br>Polymetallic gold–silver, skarn copper, polymetallic veins (porphyry-related) | Foundation auger, shafts, hand channels; mechanized bulk samples |
| <u>Transport deposits</u><br>Stream/river/alluvial, flood, beach | Polymetallic replacement, porphyry–copper, and porphyry–molybdenum | Drills |

[1]As dictated by the sample size graphs (figures 4.4 through 4.7).

The larger samples allow for inspection of the gravel or pay material. The data from the inspection or particle analysis are necessary for the design or selection of the wash plant and mining equipment.

A sampling system must provide a discrete representation of the deposit with minimal risk of contamination, dilution, or enrichment. Because sampling is so important, the following section describes applications and limitations of some of the more commonly used sampling techniques.

## Small Samples (<0.08 yd$^3$)

Drill types include core, churn, rotary (reverse circulation and conventional hammer), auger (hollow and solid stem), and sonic. Most drilling systems destroy the integrity of the individual pieces of gravel and can either liberate gold from the gravel into the sample or potentially drive it out into the voids of the host deposit. Either way, the quality of the sample may be impaired.

Drill samples have a high risk for dilution/contamination in placer deposits because of small sample size and the resulting large degree of influence of individual gold particles. The combination of small samples and contamination risks makes it necessary for evaluators to index the drill results by running bulk samples duplicating a number of the drill holes to verify the accuracy. This procedure was recommended by professional placer engineers at the end of the 19th century and is still applicable today (Thorne, 1909). At that time, test shafts were the method of choice. Today, backhoe or excavator pits would be a more likely choice.

### Core Drill

Diamond drilling, or core drilling (table 4.5), is not commonly used to sample placer deposits. This is largely because of the extreme difficulty of coring gravel. There are specific conditions, such as frozen or cemented ground, that provide the necessary stability to allow core drilling of a placer. Cost is also a factor that limits the use of the procedure. Barrels are available in diameters up to 12 in, but costs increase rapidly with size. Specific objectives that may justify coring costs include determining ground strength for the mining method analysis or possibly determining the boundaries of a placer that overlies a lode. A core-type system is preferable if an undisturbed sample is required. These samples also allow the examiner to estimate rock size changes from top to bottom, which aids in the process of equipment selection and plant design.

### Sonic Drill

The sonic drill (table 4.5) is an outgrowth of German research in pile-driving technology. The drill rig vibrates metal pipe of various sizes into the ground at relatively high speed. A vibrating head mounted on the top of the pipe induces a high-frequency vibration to the advancing face. Sophisticated hydraulics push the pipe into the ground. The system was modified for drilling by adding a sample collector with fingers similar to those in a Shelby tube to retain the sample while the rig pulls the drill string from the ground. These machines are expensive, heavy, and require high mobilization costs. They are often mounted on a tracked vehicle carrier and need two other support vehicles for compressed air, drill pipe, and tools.

The hope of the industry was that the sonic drill would be a fast, low-cost drill rig that would produce large-diameter, undisturbed samples with minimum potential for error. Although the machines are fast, often recovery of the drill pipe from the hole is difficult. Gravel tends to defeat the effectiveness of the sample retention fingers, resulting in a round, thin-walled tube surrounding a core that cannot be retrieved. Many units used in Alaska could only drill 20 ft and yielded a loose sample with undistinguishable vertical horizons. A unit used on a Montana project was outfitted with a 5-ft core barrel and a wire line. Recovery was difficult because of the broad range of particle sizes that were in the sample. The per-foot drilling costs are relatively high [$50 to $60 per foot (1988)], and availability has been limited because of

Table 4.5 Placer sampling method comparison

| Type | Gold size range (g) | Sample size range per 3 vertical ft | Capital cost range | Use cost (services) | Penetration rate (ft/h) |
|---|---|---|---|---|---|
| **Drills** | | | | | |
| Churn | <0.004 | 0.0167–0.057 bcy | \$8–\$75K | \$19–\$30/ft | 1–3 |
| Conventional hammer | <0.001 | 0.0128–0.022 bcy | \$400K | \$12–\$22/ft | 20 |
| Reverse circulation | <0.001 | 0.0128–0.022 bcy | \$400K | \$12–\$22/ft | 20 |
| Sonic | <0.005 | 0.0256–0.0606 bcy | \$500K | \$50–\$60/ft | 20 |
| Auger | <0.003 | 0.0218–0.0388 bcy | \$60K | \$12–\$16/ft | 30 |
| HS auger | <0.001 | 0.0028–0.0038 bcy | \$60K | \$12–\$22/ft | 30 |
| Core | <0.001 | 0.0057–0.0209 bcy | \$60–\$100K | \$37–\$40/ft | 5 |
| **Channels** | <0.09 | 0.111–0.444 bcy | N/A | \$5.50–\$20/h | N/A |
| **Shafts (small bulk)** | | | | | |
| Hand dug | <0.9 | 1.67–2.78 bcy | \$144/ft | \$1,440–\$288/ft | 1–2 |
| Foundation auger | <0.7 | 1.396 bcy | \$50–\$500K | Unknown | 20 |
| Bucket drill | <0.3 | 0.785 bcy | Unknown | Unknown | 5 |
| Conrad drill | >0.09 | 0.3379 bcy | Unknown | Unknown | 5 |
| KLAM | >0.3 | 0.785 bcy | Unknown | Unknown | 5 |
| **Bulk test** | | | | | |
| Backhoe | Unlimited | 0.074 to unlimited lcy | \$25–\$75K | \$25–\$75/h | 10 |
| Excavator | Unlimited | 0.62 to unlimited lcy | \$50–\$410K | \$95–\$125/h | 60 |

*Note.* Sample size dictated by predominant gold particle weight. bcy, bank cubic yards; lcy, loose cubic yards; K, thousands.

repairs and maintenance. The drill appears to work well in frozen or cemented ground but performs poorly in saturated deposits. Use of the drills in the placer industry is quite low, with maximum activity seen in Alaska during the late 1980s.

## Churn Drill

The churn drill (table 4.5) has been the standard of the industry for nearly 50 years. The name of this drill can vary greatly, depending on the region in which it is used and the manufacturer. It is known as a placer drill, cable tool, Keystone®, Airplane®, or Hillman® prospector drill, all of which were initially competitive products

**Table 4.5—Continued**

| No. of excavation crew | No. of sample | Man hours per foot | Machine effective depth (ft) | Maximum depth | Ideal conditions |
|---|---|---|---|---|---|
| 2–12 | 2 | 1.1.3–16 | 300 | 60 | Saturated; loose, <cobble-size gravel |
| 2 | 3 | 0.25 | 3,000–4,000 | 60 | Tight, frozen, cemented, dry, multi-size gravel |
| 2 | 3 | 0.25 | 3,000–4,000 | 60 | Tight, frozen, cemented, dry, multi-size gravel |
| 3 | 2 | 0.25 | 20–70 | 60 | Tight, frozen, cemented, dry, multi-size gravel |
| 2 | 2 | 0.13 | 200 | 60 | Tight, dry, <cobble-size gravel |
| 2 | 2 | 0.13 | 200 | 60 | Tight, dry, <pebble-size gravel |
| 3 | 1 | 0.8 | <100 in gravel | 60 | Tight, cemented, frozen, dry, multi-size gravel |
| 1–2 | 2–5 | N/A | 30 | 10 | Tight, dry, multi-size gravel (preferably cobble-size or less |
| 2–3 | 2–3 | 6–20 | 30 | 60 | Dry, tight, no boulder, sand/pea gravel lenses |
| 1 | 2–3 | 0.15–0.20 | 50 | 60 | Dry, tight, no boulder, sand/pea gravel lenses |
| 4 | 3 | 1.4 | 50 | 60 | Dry, tight, no boulder, sand/pea gravel lenses |
| 4 | 3 | 1.4 | 200 | 60 | Dry, tight, no boulder, sand/pea gravel lenses |
| 4 | 3 | 1.4 | 200 | 60 | Dry, tight, no boulder, sand/pea gravel lenses |
| 1 | 3 | 0.4 | 17 | 17 | Damp, tight ground, multi-size gravel, not cemented or frozen |
| 1 | 3 | 0.07 | 40 | 40 | Damp, tight ground, multi-size gravel, not cemented or frozen |

built by various companies. The first of these drills were powered by steam and operated near the turn of the century. Later units have employed various power plant types.

The initial step consists of drilling a hole and driving a casing with a drive shoe, ranging from 5½ to 9¾ in. in diameter, into the ground. A bit is lowered into the casing, and the material in the casing is pulverized. A few inches to 1 ft of material is always maintained inside the casing between the shoe and the bit face.

The bit is then removed, and a sand pump is put in its place to remove the pulverized material. In a dry hole, water may need to be added to allow pumping. Next the sample is measured for volume, then concentrated, and the gold recovery is determined for each interval. The drive shoe is advanced, and the cycle is repeated to

bedrock or to a predetermined depth. During the process, the operator has to be careful not to drill beyond the drive shoe and the casing. If done correctly, each sample represents a specific volume of uncontaminated material.

This drill can encounter problems when a deposit contains boulders that the drive shoe cannot penetrate. At that point, the bit must precede the drive shoe through the boulder. When the bit breaks through the boulder and returns into the gravel (without the casing), there is an extremely high risk for sample enrichment. Boulder pavement of this type decreases the reproducibility of the sample. Because the gravel is pulverized in the process, gold particles that normally could not be recovered with the use of placer techniques may be liberated, and anomalously high gold recoveries may result. The small sample size from a 3-ft interval only further enhances the risk of sample contamination because of the influence each small gold particle may have on the sample value. Additional errors may be encountered where drilling takes place in unconsolidated deposits. Recoveries may exceed amounts that can be attributed to both the original volume and the calculated swell. Operators must take extra special care to monitor the volumes recovered and be on the lookout for excess sample recovery.

Problems notwithstanding, this drill is still the most efficient in deposits containing small gold particles, but its effectiveness is greatly enhanced in uniform small- to medium-size gravels and sands.

### Dilution/Contamination

When a churn drill is used to obtain samples, the evaluator must be aware of the potential sources of dilution and contamination. Dilution occurs when waste material flows into the sample or gold particles are lost from the sample, thus reducing the value of the sample interval. Contamination occurs when extraneous gold particles are collected and erroneously high values are recorded for the interval. Much of the accuracy of the sample recovered depends on the driller.

On a project in Idaho, drill holes penetrated an aquitard into an underlying artesian aquifer containing substantial pressure. The flowing water from the depressurizing system carried the sand-size particles from the artesian zone up the casing, leaving the gravel behind. The volumes recorded indicated recoveries exceeding 200 percent of the expected sample volume. The actual sand fraction was typically only 30 percent of the total gravel deposit. Therefore, the recovered sample represented only the fine fraction of a volume of gravels at least four to five times the actual drill-hole volume, which rendered the drilling results useless for estimating placer value.

Other difficulties in estimating values can be created by varying rates of swell in the gravel. As the shoe is driven through the gravel, the material is disrupted (figure 4.8) (Thorne, 1909). The outer edge of the shoe collects a larger volume of material than would fit into the inner diameter of the casing. As the gravel flows into the casing, the particle packing is affected. The swell created by gravel movement is added to the swell created by the constriction at the casing from the drive shoe, which causes the gravel to rise in the casing at a faster rate than the casing is driven into the ground. This creates difficulty in logging the hole, and the results become questionable.

Early placer engineers relied on the Radford factor (table 4.6) to adjust some of these volumetric problems that are swell-induced. If one assumes uniform swell factors throughout each deposit, the values seem reasonable; however, tests of swell factors at placer deposits have shown that values at a single deposit within a 20-acre claim can vary between -10 percent and +48 percent.

There has also been concern within the placer industry that in water-saturated holes, the vibration and suction induced by churn drilling cause gold to fall to lower levels within the deposit. The results of the vibration-induced gold migration would be that the gold particles tend to settle on bedrock, clay layers, or other false bedrock layers. Thus, the values reported at bedrock and similar impervious layers may be significantly higher than they actually are. In the cases of flowing ground, drillers may leave more material in the casing as a plug to restrict the flow of incoming material. That technique becomes problematic because if too little sample is left in the casing, too much sample may be collected; conversely, if too large a plug is left, the plug will not ascend, the plug/casing combination will act as a piling, and too little or no sample will be gathered.

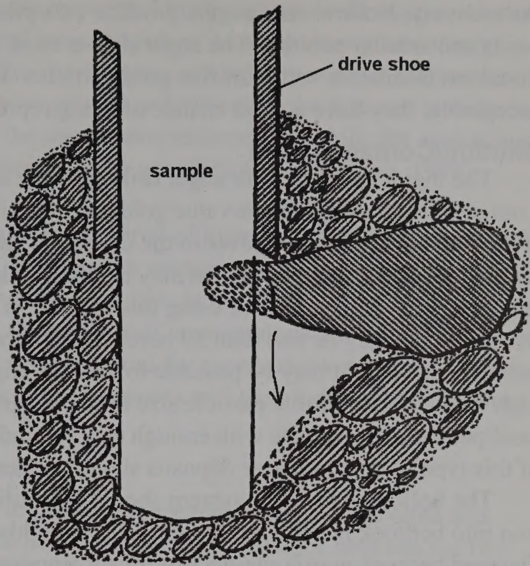


Figure 4.8. A flat rock struck by the shoe and forced ahead will also drive the gravel to one side (Thorne, 1909, p. 358).

Table 4.6 Radford Factor (MacDonald, 1983)

| Diameter of cutting edge of shoe | Factor | Edge of shoe | Factor |
|---|---|---|---|
| 4.00 in (10.16 cm) | 0.077 | 6.00 in (15.24 cm) | 0.173 |
| 4.25 in (10.80 cm) | 0.086 | 6.25 in (15.88 cm) | 0.187 |
| 4.50 in (11.43 cm) | 0.097 | 6.50 in (16.51 cm) | 0.203 |
| 4.75 in (12.07 cm) | 0.108 | 6.75 in (17.15 cm) | 0.218 |
| 5.00 in (12.70 cm) | 0.120 | 7.00 in (17.78 cm) | 0.235 |
| 5.25 in (13.34 cm) | 0.132 | 7.25 in (18.42 cm) | 0.252 |
| 5.50 in (13.97 cm) | 0.145 | 7.50 in (19.05 cm) | 0.270 |
| 5.75 in (14.61 cm) | 0.158 | | |

## Auger Drill

Auger drills (table 4.5) are available in two types but vary in size. The solid-auger drill depends on recovering gravel on the flights. This is done by pulling the auger out of the hole and cleaning the flights into a barrel or by collecting the material as it is retrieved from the hole. The other type is the hollow-core auger, which collects an undisturbed sample in a collection tube. Both types depend heavily on the gravel character—the more uniform, cohesive, and smaller the material sampled, the better

the recovery. Hollow-core augers produce exceptional, undisturbed cores of beach sands and smaller pebbles. The auger drill is most effective in low-energy depositional environments with ultrafine gold particles. Where small samples are acceptable, they have a good chance of being representative of the deposit.

### Dilution/Contamination

The major problem with auger drilling is the small size of the sample produced. Loss or gain of a single high-value gold particle will severely affect the sample value. If the particle size of the gravel in the deposit is large with respect to the auger flight widths, much of the fine material may be lost, while a significant area around the hole will be disrupted. Recoveries using this method in predominantly cobble/boulder environments may be less than 50 percent, and recoveries as low as 20 percent would not be surprising. It may be possible to load the flights with fines and set erroneously high values and unusable particle size ratios. Auger drills should be confined to dry, sand/pebble-size deposits with enough clay to bind the particles together. General use of this type of drill in placer deposits should be done with great discretion.

The hollow-core auger system should be confined to sand/silt samples. Penetration into bedrock is quite limited unless it is highly altered, soft, or heavily fractured. Fissured bedrock may contain a significant amount of the gold in a placer deposit, and neither of the auger systems would be satisfactory for sampling that portion.

## Rotary Drill

Rotary drills utilize a rotating drill stem and an impact hammer or tricone bit. The sample is conveyed to the surface by compressed air where a cyclone collects the sample.

There are two basic designs used with the down-hole hammer system. In the conventional design, which is commonly used to drill water wells, compressed air travels down a single-walled pipe to the hammer and carries the cuttings up the annulus between the drill stem and the hole wall. In the reverse-circulation system, a hollow double-walled pipe is used. The air travels to the drill head between the walls of the drill rod, and the sample is raised to the surface through the center of the rod. Depending on the hammer, the sample may actually enter the pipe 0.25 to 5 ft above the hammer rather than at the bit face. A tricone bit is recommended for use with either system in softer material such as clay, shale, or unconsolidated gravel.

Modifications of the two previously discussed systems are the Barber dual-rotary system and the Schramm drill. The Barber dual-rotary system turns the casing in one direction while the hammer turns in the other. By carrying the casing with the hammer, loss or gain from the hole wall is minimized.

The Schramm drill system drives the casing in advance of the hammer. Like the churn drill, the casing has a drive shoe. The material inside the casing is drilled out by a conventional down-hole hammer. As is the case with the churn drill, if too much gravel is left in the casing, the casing–gravel combination will resemble a piling and push the gravel aside as it is pounded down.

Costs for rotary drill systems range from $12 to $22/ft. Where drilling is fast, contractors may opt to drill by the hour (approximately $175/h), which can result in a total price as low as $3.50 to $4.00/ft.

Tests performed in the Yukon (Clarkson, 1998) indicate that conventional down-hole hammer drills should be used with a full-length casing system in thawed, unconsolidated, and/or saturated ground. The distance the casing must be driven ahead of the

hammer depends on the rate of sample recovery. Flowing ground will require substantial distance between the hammer and the casing shoe; however, compaction may occur as described under churn drills. The reverse-circulation system is only recommended for drilling cemented or frozen gravels or for locating the distance to bedrock. Recovery statistics associated with the use of reverse-circulation drills for evaluating placer deposits have proven the technique to be unsatisfactory (Clarkson, 1998).

### Dilution/Contamination

All variations of rotary drills run the potential of liberating gold from the gravel particles pulverized during drilling. If operators use too much air to extract the cuttings, the fines may be forced into voids or cavities in the drill-hole wall when using the conventional hammer drill, and this will result in anomalously low gold recovery. In either drill system, drillers risk a high potential for excess recovery of the fine fraction of the deposit by not using a casing. The results will then indicate higher values than actually exist.

## Reconciling Drill Results

It is critical in all drill systems to measure the sample volume recovered and compare that with the predicted drill-hole volume. The difference between the two volumes will be a function of swell, contamination, and/or loss. Any of these factors can result in an error that will affect the projected economics of the property. This is especially true because of the small size of the samples. When a property is drilled and these differences occur, it is imperative that they be resolved, or the results must be discarded. If no satisfactory resolution can be reached and the drill information is critical, the hole must be redrilled. A method of resolution used with churn drill results (Wells, 1969) of reconciling errors follows:

More than 100 percent recovery:

$$\frac{\text{theoretical volume}}{\text{measured volume recovered}} \times \text{ value of gold recovered} = \text{corrected value.}$$

Less than 50 percent recovery:

multiply value of gold recovered x 2 = corrected value.

Wells emphasizes that although this is a method to solve discrepancies in sample recovery, it can be applied in varying degrees dependent on the experience and judgment of the engineer. All earlier drill results should also be scrutinized since they were most likely "adjusted results" based on recovery problems encountered during the drilling program.

## Hand Samples (0.08–0.35 yd$^3$)

As the predominant particle-weight distribution gets larger than the milligram range, the samples provided by drilling become too small to escape the influence of the nugget effect. The evaluator must consider methods that will produce a somewhat larger sample at a lower cost. For predominant gold weights between 0.02 and 0.09 g, the graphs (figure 4.5) show that the sample should range between 0.15 and 0.30 yd$^3$. This size is applicable to channel or bulk samples taken by an experienced sampler. The costs can be high because of the time required for sampling. Where manual labor is readily available at a low cost, this method should be considered. In some cases where terrain or regulations restrict use of motorized equipment, hand samples cannot be avoided and are the only alternative.

Examiners should begin by excavating a pit approximately 4 ft x 4 ft x 3 ft deep or cutting a trench in a natural exposure of the placer material. The sample should be cut from the side of the excavation as a channel; the size of the channel will be determined by the sample volume required (figure 4.9). The sample face should be cleaned to remove any disturbance or possible contamination. Many samples are cut from the bottom up to control contamination from raveling and sloughing of the channel walls. In unconsolidated material, it may be easier to cut the sample from the top down if the

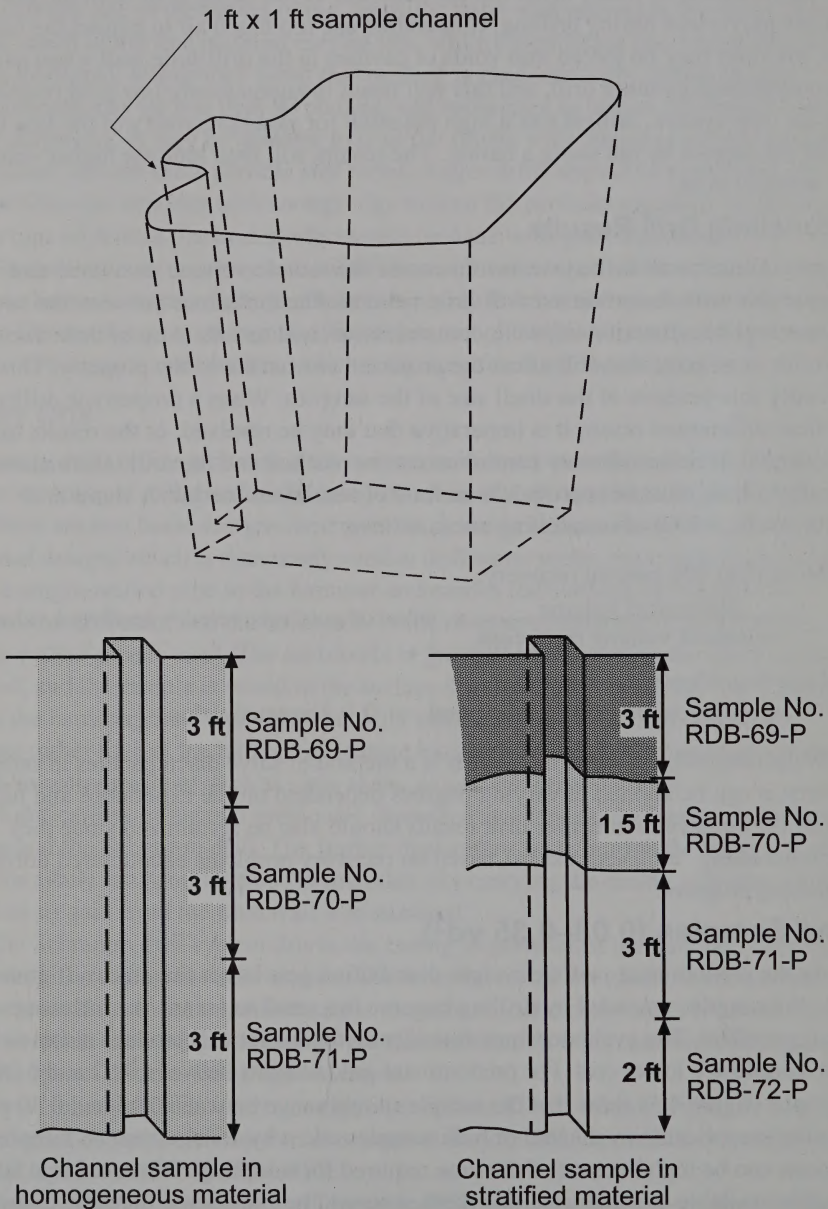



Figure 4.9. Schematic diagram showing a test pit and sample channel.

material is unstable. The samples are usually collected in buckets for security and handling ease. The sample should be representative, and the volume should be dictated by the graphs (figures 4.4–4.7) of predominant gold weight and sample size. Choices of channel size (length x width x height) should reflect one of the following:

$$\frac{1\text{ ft} \times 1\text{ ft} \times 3\text{ ft}}{27\text{ ft}^3/\text{yd}^3} = 0.11\text{ bcy}; \frac{1\text{ ft} \times 2\text{ ft} \times 3\text{ ft}}{27\text{ ft}^3/\text{yd}^3} = 0.22\text{ bcy; and } \frac{2\text{ ft} \times 2\text{ ft} \times 3\text{ ft}}{27\text{ ft}^3/\text{yd}^3} = 0.44\text{ bcy.}$$

The hand-channel method gives the evaluator the most control over the sample with the least margin for error. Safety of the sampler is always a concern. Caving trenches or pits are a dangerous reality. If the working surface is below the water table, the likelihood of caving is almost a certainty. The evaluator should make every effort to minimize the risk with shoring and trench liners. In saturated, unconsolidated, or deep overburden, this method consumes both time and money, and better methods are available.

**Dilution/Contamination**

Hand sampling methods can secure a valid sample in caving or loose ground. The integrity of the samples can be assured, but as with other sampling methods, special care must be taken to ensure accurate samples. Boulders can create severe problems for the sampler, especially when they are significantly larger than the sample channel or cut. They are part of the sample, but not all of them can be collected as they may be too large to move.

The best method is to remove all of the finer material and leave the boulders. The calculated volume of the sample must reflect the portion removed plus the volume of boulders that should have been sampled. The gold recovered must be applied to the entire sample volume. A boulder factor (percentage of total volume occupied by boulders) should be estimated and recorded in the sample notes. That number will also be used in the design of the wash plant. In many of these boulder concentrations, less than 30 percent of the bcy resource can actually be physically processed during a sampling program of this kind.

## Small Bulk Samples (0.35–2.75 yd³)

As the gold particles increase in size into the tenths-of-a-gram range, it becomes increasingly difficult to evaluate a placer deposit in a cost-effective or timely manner with the use of manual labor. Although drilling was prevalent during the period when bucket dredging predominated, the results of drilling were verified with hand-dug and cribbed shafts (Thorne, 1909). Shafts have limitations and are not particularly effective in saturated ground or in deposits containing large boulders. Shaft excavation rates can be expected to range from 1½ to 3 vertical ft/day in a completely cribbed shaft (4 ft by 5 ft) (Peele, 1941). Depths of more than 100 ft are unrealistic; most shafts are between 25 and 35 ft deep and are limited to reasonably dry situations. If shaft sampling is chosen as the preferred option, the size of the shaft is a function of the size of the evaluator, the boulders, and the budget. Common shaft sizes evident today are 5 ft by 5 ft = 2.7 bcy/3 ft vertical; 3 ft by 6 ft = 2.0 bcy/3 ft vertical; 4 ft by 4 ft = 1.8 bcy/3 ft vertical; and 6 ft by 6 ft = 4.0 bcy/3 ft vertical.

Early reports from drilling companies indicate that by the end of the 19th century hand-dug shafts were too expensive and time-consuming to justify use in anything more than the verification of drilling results. In a hand-dug shaft program, the entire volume of gravel removed from the shaft on 3-ft intervals would be processed as

excavated. Support would be either timber or caisson, depending on availability or cost. Dewatering was accomplished with electric or pneumatic pumps in order to minimize the ventilation risks to workers that internal combustion engines pose. Unless labor is cost-effective and available, hand-dug shafts are not recommended.

### Dilution

Ground control is typically good if cribbed shafts can be dug. Although the risk of dilution should be noted, it is typically not a large problem. Examiners can achieve the same goal of a medium-volume sample by using machines that drill or excavate small-diameter shafts (3 to 5 ft) given suitable ground conditions.

### Foundation Drill or Auger

The foundation drill, or auger (table 4.5), is similar to a small crane or tracked dragline. Instead of a boom and cables, it has a direct drive to a sliding square shaft that has a 4- to 5-ft-diameter auger on the end. Examiners start the sampling sequence by drilling 5 ft and then pulling the auger out of the ground where the flights are cleaned into a drum for processing. The sequence is repeated for the next sample.

An auger is most likely to be successfully used in coherent, somewhat clayey deposits, and in suitable materials auger sampling can be highly efficient and accurate. Because the system requires the auger to be removed each time, a caving hole in loose materials will result in contamination. Unconsolidated gravel and saturated sites usually do not provide a good sample. Boulder pavement will usually require that a driller be hoisted down the unsupported hole where the large boulders are drilled and blasted. Sample accuracy, hole stability, and safety are of the utmost concern with any depth below 10 ft. Since mobilization on- and off-site is expensive due to the weight of the equipment, extensive resources are necessary to justify the expenditure.

There are a few other types of drills capable of producing 3- to 4-ft holes in placer deposits, but most of these pit drills are confined to foreign exploration. Therefore, these drills are not an option to be considered for evaluation of domestic deposits.

### Calweld Drill (Rotary Bucket Drill)

The Calweld drill (table 4.5) is truck-mounted and produces a hole approximately 1½ to 8 ft in diameter. Each sample is collected in a bucket that has cutters on the side. The sample is protected from contamination. The system will handle boulders up to 11.8 in. Like the foundation auger, the system works best in dry, consolidated deposits up to cobble size. Rates of advance in ideal conditions range from 195 to 227 ft/8-h shift (MacDonald, 1983). Cased holes in wet ground show drilling rates of less than half that.

### Conrad Drill

The Conrad drill (table 4.5) operates by rotating the casing into the ground with its own weight providing the necessary downward pressure. The diameter is typically 19.7 to 23.6 in, which would yield samples as large as 0.338 bcy (3-ft vertical intervals).The sample is removed with the use of a clamshell or pivoting bucket (MacDonald, 1983). The system handles rock as large as 9.8 in. in diameter and can be mounted on trucks, tractors, platforms, or pontoons. The rate of advance appears to range from 1 to 4 ft per hour (MacDonald, 1983).

### KLAM Drill

The KLAM drill (table 4.5) is an air-activated gravity drill designed to excavate a 24-in-diameter hole to a maximum depth of 100 ft. A similar unit called a PAR-X is cable-activated and digs a hole approximately 30 ft deep and 28 $in^2$ without a casing. Both of these units have been listed as mechanical shaft-excavation machines. Their rate of advance is 2 to 20 ft/h for the KLAM and up to 35 ft/8-h shift for the PAR-X (Wells, 1969).

A sample would be collected every 3 ft. Without casing, errors can occur with sample recovery volumes and contamination. Early evaluators welcomed the small-diameter shaft as an opportunity for accurate log keeping. Today's work rules do not allow physical entry of unsupported small-diameter shafts for safety reasons. This same type of system is also termed caisson digging equipment (Richardson, 1992). The Bade drill made in Germany, as well as similar equipment made in Canada, also provides lined holes with a clam-type extraction (Richardson, 1992).

All systems of this kind are expensive (approximately $1,000,000) and heavy if casing is used. Mobilization fees and permits can severely limit the distance that this equipment can be moved.

## Bulk Samples (>2.75 $yd^3$)

If the cumulative weight distribution analysis shows that the most influential gold particle weight range is greater than 0.9 g, the deposit may not be adequately sampled without the use of equipment capable of producing samples (per 3 vertical ft) larger than 2.8 bcy. Often bulk samples are 5 $yd^3$/3 vertical ft or larger.

Bulk samples differ from previously discussed sampling methods. Each of the previous methods collects a volume measured in bcy, or an *in situ* volume. When a bulk sample is taken, the volume of the material removed is expanded as a void is created between the particles. The difference between the volume of the sample in place and the volume of the sample excavated is calculated as the percentage swell.

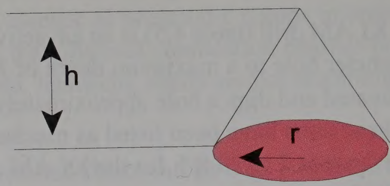
The swell commonly varies throughout placer deposits. Fine sand may swell only +10 percent, but a boulder zone may show a swell of +40 percent. It is important for the evaluator to know the swell of the pay gravel and the overburden. It is quite difficult to determine a single number for a variable deposit, but a reasonable estimate should be attempted.

On a small scale, the evaluator may cut a sample such that the void created is measurable. For instance, a 1-$ft^3$ sample has been used successfully in the past. In this situation, the top of the sample is leveled, and the face is prepared for the excavation. A sample measuring 1 ft on each side is removed from the wall of the deposit. The volume removed is loosely placed in a bucket or box so the new volume can be measured. The swell is calculated as the percentage of change:

$$\text{percentage swell} = \frac{\text{volume loose - measured volume of the hole}}{\text{measured volume of the hole}} \times 100.$$

It can also be measured by preparing a flat surface and excavating a hole of known volume. The excavated material is dumped to form a cone. Evaluators using the width of the base and the height can calculate the volume with the following formula:

$$\text{volume} = \frac{\pi r^2 h}{3}$$




They can calculate the percentage of swell by using a similar formula:

$$\text{percentage swell} = \frac{\text{volume of cone - measured volume of the hole}}{\text{measured volume of the hole}} \times 100.$$

Resources are measured in bcy, whereas process rates and costs are calculated in lcy. The number of lcy that must be processed to recover the valuable portion of a bcy becomes important when examiners reach the completion of the feasibility analysis of a placer deposit. The following formula, which provides an increase in volume, but not an increase in value, is used in the conversion:

$$(1.0 + \frac{\text{percentage swell}}{100})\ \text{bcy} = \text{lcy}.$$

The choices of available excavation equipment are limited by deposit characteristics. These include depth, degree of consolidation, size of materials, static water level, rate of inflow, and equipment availability.

The size of a track hoe or excavator used is usually dictated by the maximum expected excavation depth; thus the reach of the machine is the deciding factor. If the deposit is shallow (<12 ft), a rubber-tired backhoe may meet the needs if the required sample is not too large. However, if the gold or other commodity of interest is covered by boulder pavement, a small backhoe may have the reach but not the necessary breakout force to excavate into the boulder pavement; in such cases a larger unit is required. The upper size limit of the excavation equipment is usually dictated by cost; however, many areas may limit the equipment that can be mobilized to the site.

The sample site is usually pre-stripped of topsoil or vegetation. An important cost-saving feature for reclamation of the site is storage of all stripped material uphill from the deposit, as shown in figure 4.10. After the ground is prepared, the sample(s) should be excavated from successive 3-ft layers and stockpiled on a hard surface such as plywood for ease of recovery; this provides minimal risk from dilution or contamination. The sample may also be loaded directly into a dump truck for hauling to the process area. The swell for each sample should be measured using one of the methods discussed previously.

If the hole created by sampling is too small to continue sampling deeper layers, the excess material generated by enlarging the hole should be removed and stockpiled with the overburden. This process should be repeated for each sample in 3-ft intervals, including the bedrock. After a few sites have been processed and the pay zones have been identified, future sampling may be confined to the pay zones. Preferably, one 3-ft zone above and one below the identified pay zone should continue to be sampled to verify that the pay zone has been adequately delineated and that no changes

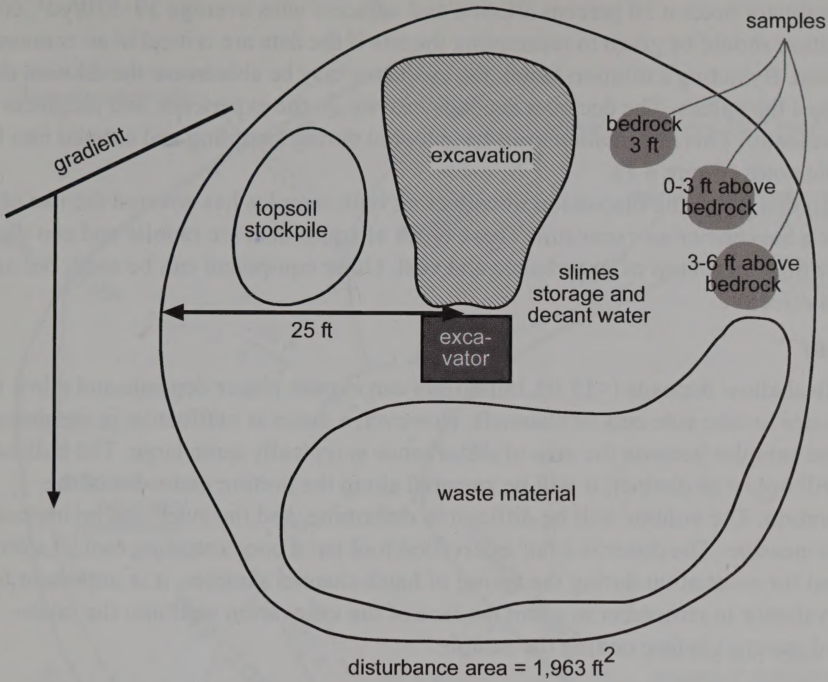



Figure 4.10. Typical disturbance arrangement of a placer test site, where the gold-bearing interval is 6-ft thick.

have occurred. This will provide confidence in the process and eliminate questions of procedure. If the character of the deposit changes, the evaluator should increase the number of sample lines and decrease the spacing to verify the boundary between the barren or non-economic overburden and the pay zones.

Evaluators must calculate and record each sample size by first measuring the dimensions of the excavation (bcy) and bucket volume dumped (lcy) and then calculating the swell factor of each sample using these volumes. This information will be used in the calculation of reserves, mining economics, and mine planning. Incorrect swell measurements could severely affect the economics of the project.

## Dilution

Whereas most of the previously described methods will give a semi-controlled sampling environment, the bulk sample will more closely mirror production problems. To minimize the possibility of error in this process, it is imperative that the evaluator estimate the amount of contamination in each sample. This contamination most commonly occurs as waste layers caving into the bucket as the sample is removed. By estimating the percentage of dilution or waste vs. pay volumes in each sample, the evaluator can estimate the sensitivity of each of the samples to inaccuracies of the process. Normally, wet holes are more of a problem than dry holes because they are more prone to caving. For example, if recoveries indicate gold values of $5/yd$^3$ on a property that had estimated mining costs of $5/yd$^3$, this material would be classed as overburden or waste and would not be included in the reserves; however, if

the evaluator notes a 50 percent dilution and adjacent sites average \$9–\$10/yd$^3$, consideration should be given to resampling the site if the data are critical to an economic decision. By noting a dilution factor, the evaluator may be able to use the dilution data to adjust the values. The decision depends heavily on the experience and judgment of the evaluator. This information must be gathered during sampling and entered into the sample notes (figure 4.1).

To this point, the discussion of collecting bulk samples has covered the use of either a backhoe or an excavator. These types of equipment are mobile and can dig a hole with a minimum of disturbance and cost. Other equipment can be used, but are not as effective.

## Dozer

In shallow deposits (<15 ft), bulldozers can expose placer deposits and allow the evaluator to take side cuts or channels. However, a dozer is ineffective in obtaining precise samples because the area of disturbance is typically quite large. The bulk sample will not be as distinct; it will be smeared along the bottom and sides of the excavation. The volume will be difficult to determine, and the swell can be impossible to measure. The dozer is a fair excavation tool but a poor sampling tool. If a dozer is used for excavation during the taking of hand-channel samples, it is important for the evaluator to remember to clean the face of the excavation well into the undisturbed material before cutting the sample.

## Draglines

Many placer deposits have old draglines on site, as they have consistently demonstrated low operating costs. They can be as effective as an excavator, but if they are not on site, the cost of mobilization can be very high. Most draglines require at least two transport units to be moved: one for the machine and one for the bucket and boom. Larger draglines may require three or four transport vehicles, depending on the weight. If an evaluator is considering using a dragline, thought should be given to the distance to the deposit and the distance between holes. Draglines, like dozers, create more disturbance. If the operation is going to use a dragline, the samples should closely reflect gold recoverability under actual mining conditions. However, the samples will not reflect the potentially recoverable gold trapped in hard bedrock that the dragline may not be able to penetrate. Dragline samples will be as good as those obtained with an excavator, but because penetration is a function of the weight of the bucket, draglines smaller than 2- or 2½-yd capacity may not be able to sample tight ground. Tight boulder pavement (4-ft-diameter boulders) may resemble reinforced concrete to a dragline.

## Wheel Loaders

Wheel loaders can be as effective as excavators in shallow, dry, loose ground. The wheel loader was designed for loading loose material and advances easily into stockpiles. If gravel deposits do not exceed cobble-size material and are unconsolidated, the wheel loader can be effective. In well-consolidated deposits with boulders or hard, ragged bedrock, a wheel loader will not operate efficiently.

As with the dozer and dragline, operators need to disturb a substantial area in order to secure samples—the deeper the target, the bigger the area of disturbance.

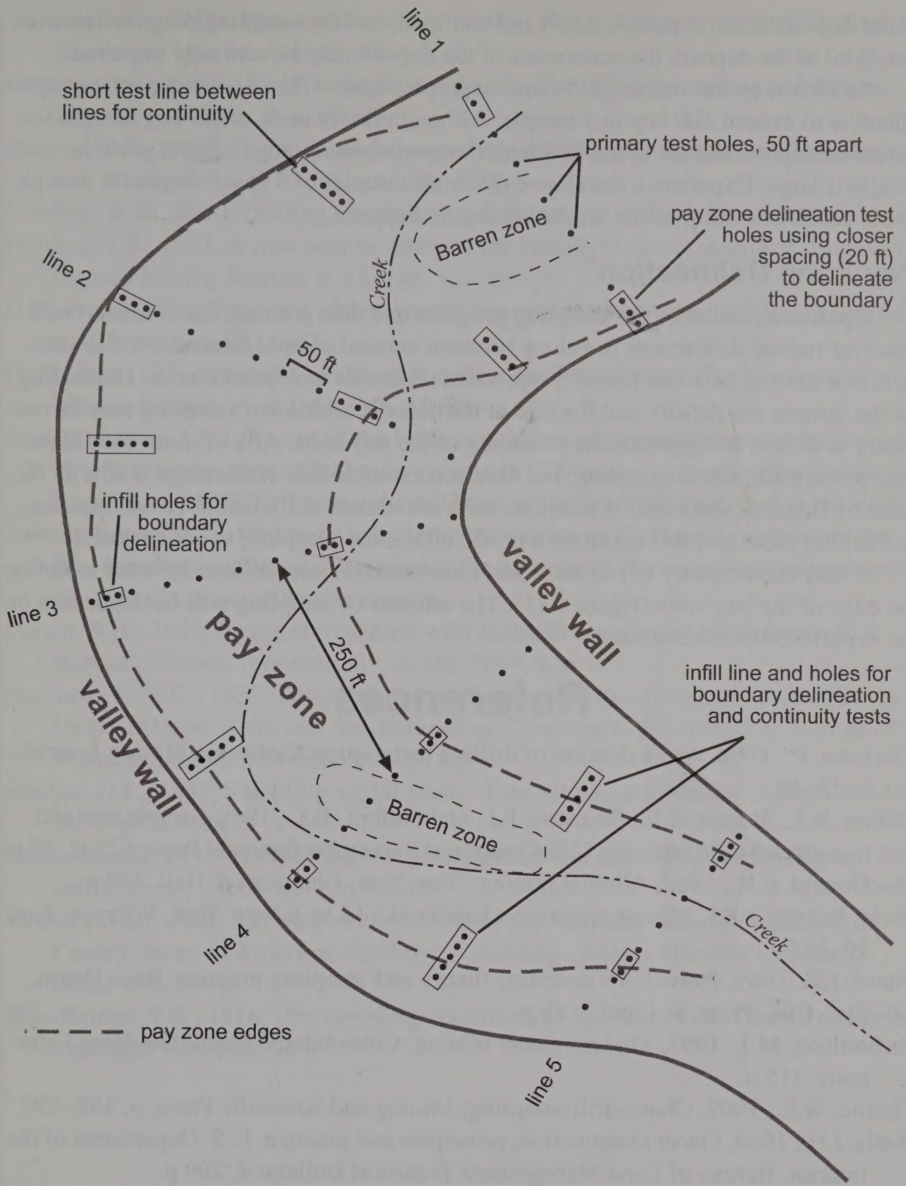



Figure 4.11. Pay zone delineation through additional sample holes.

In dry, consolidated deposits, the wheel loader can provide samples of varying sizes with enough selectivity to allow calculation of the swell factor. Because of the need to construct a ramp for access, the maximum effective depth for taking samples from the surface should not exceed 10 ft.

## Maximum Sample Size

The minimum size of the sample is limited by the nugget effect, while the upper limit is dictated by cost and the effect the program may have on the future mineability

of the deposit. If the deposit is small and confined, and the sampling program removes one-third of the deposit, the economics of the deposit may be seriously impaired.

As shown on the coarse-gold-particle graph (figure 4.7), it is not realistic or cost-effective to exceed 300 bcy in a sample. Although rarely used, a 300-bcy sample size would be appropriate for deposits where the predominant range of gold particle weight is large. Experience has shown that bulk samples of 5 bcy/3 vertical ft provide good, consistent samples for most coarse-gold deposits.

## Pay Zone Delineation

Upon completion of the sampling program and data plotting, the evaluator will discover radical differences in values between vertical sample intervals, while similarities will exist between laterally equivalent intervals in adjacent holes. Depending on the sample site density and the size of the deposit, additional sampling may be necessary to define the approximate boundary of the pay zone. Any of these conditions may prompt additional sampling, but the decision to do this at this stage is strictly dictated by finances and need. If adequate reserves remain sufficient to cover operating and capital costs and still maintain a profit, additional sampling is not critical.

It may be necessary to run short test lines between sample lines in order to define the edge of the pay zone (figure 4.11). The amount of sampling will be dependent on the experience of the evaluator.

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# Chapter V: Sample Processing

# Sample Processing

## Material Handling

During the evaluation of a placer deposit, a considerable amount of money will be invested in sampling; each sample may have a total cost ranging from $800 to $2,000. Inaccuracies resulting from negligence in handling are absolutely intolerable. Most commonly, mishandling of samples results in dilution or contamination, and sometimes samples are salted. During processing, incomplete or inaccurate methodology as well as errors caused by sample splitting can lead to inaccurate results.

The severity of each of these problems is directly proportional to the sample size. If the samples are small, a single flake of gold in the 1-mg weight range will have a significant effect. If the sample is large enough to overcome the nugget effect (Chapter IV), only significantly larger gold particles will have an effect.

Correct handling procedures are influenced by the sample size. Drill samples are usually small and can easily be placed in 5-gal plastic buckets. Channel samples fall into the same category; however, each sample may require 20 to 40 buckets. Plastic buckets are convenient because of their strength and light weight. The filled buckets are typically in a weight range that can be easily handled if processing is done by manual labor, and with tight-fitting lids, they also provide a well-protected sample. Larger bulk samples typically need to be stored briefly prior to processing. They usually require machine assistance for loading into the wash plant.

## Dilution or Contamination of Sample

Sources of errors in sampling were described in the previous chapter. However, improper handling can introduce additional errors at any later stage. If the evaluator has temporarily stored a bulk sample on the ground, and some of this extraneous material is gathered with the sample when it is moved, the sample results will certainly be affected. If the sample is placed on barren overburden and some of this material is collected as the sample is retrieved, the sample grade will be diluted. On the other hand, if it is placed on gold-bearing gravels, the sample grade could be enhanced.

A good procedure for avoiding this problem is to load the sample directly into a dump truck or a large, seamless plastic tub for transport to the processing area. An even better method would be to place the sample directly into a wash plant for processing. This works well in shallow, dry ground. In wet, caving ground, the operator must secure the samples as fast as possible before the hole caves. Consequently, samples must be temporarily stored near the sample site or excavating machine. In this case samples should be placed on plywood or strand-board sheets, so that they will be easier to retrieve without either dilution or contamination. Heavy sod or thick grass cover may also be used to provide a surface that minimizes contamination during retrieval, but some sample material will likely be lost.

At the sample processing site, an adequate base that does not contain gold must be provided for sample storage. A clay bed, concrete, or even wood sheeting would make an acceptable floor for the sample repository.

## Incomplete Sample Processing

If a highly porous sample is placed directly on the ground for a long period, the heavy minerals may settle toward the bottom. Precipitation may enhance the settling

rate and depth. If the evaluator does not retrieve the entire sample or leaves the bottom few inches of the sample on the ground, it will be undervalued. When the next sample is placed on this site, the same sample handling procedures may further enrich the surface value of that site. At some point, some of the concentrated values will be included in another sample. This will give erroneous values to all of the samples, biasing the values upward in some and downward in others, which will affect the economics of each of the reserve blocks.

It is imperative that evaluators process all of each individual sample completely before beginning another. The transfer or repository site must be cleaned thoroughly between each sample processing so that cross contamination is minimized.

## Splitting

Evaluators who are not experienced in placer operations may want to split placer samples to verify continuity or reproducibility or to reduce the amount of material that must be handled in the sample process. If all gold particles in a deposit are extremely small, sample splitting may not cause an appreciable difference in the grade, particularly if the deposit is fairly homogeneous. However, most placer deposits are not homogeneous, and the rarity of gold particles greatly aggravates the problem.

The basic rule of sampling is: **Do not split placer samples or lode gold samples that contain visible gold; take duplicates instead.** This is true even when the gold is only visible in concentrates. Splitting placer samples severely reduces the reproducibility of the results. Reproducibility decreases further as the gold particle size increases.

After the evaluator has determined and collected the correct size sample, every grain of the sample should be processed. Lode deposit sampling techniques and placer sampling techniques are not interchangeable.

## Salting

"Salting" of samples means the intentional or unintentional enrichment of the sample. The ingenuity of a promoter, landowner, or claimant when deliberately influencing the value of a marginal claim or deposit is legendary. The property evaluator must consistently maintain security on samples, sample sites, and concentrates at all times. Concentrates should always be under lock and key when not being processed or studied. To eliminate the suspicion of or the potential for salting a sample, it is critical that those individuals who have the most to gain from an above-average grade determination be denied any proximity to the sample site, samples, or concentrates until the property evaluation is finished.

Over the years, perpetrators of salting have devised and employed various and ingenious methods, including enriching the sample through physically placing gold at the sample site, sprinkling free gold onto the sample after it is collected but before processing has begun, and even loading the gold into a cigar or cigarette and then dropping the ashes into the wash equipment during processing. Gold maybe placed in the wash plant before processing. Fine gold may be injected into the sample concentrates with a hypodermic needle. Nuggets may be tossed or shot into the sample or wash plant by hand or with a slingshot. In earlier times, gold was rolled up in shirt sleeves or pant cuffs and added to the sample or wash plant while the salter appeared to be simply cleaning the clothes.

As the sample size increases, more gold is needed to have a noticeable effect on the value of the sample. Consequently taking numerous large samples makes it not only difficult to salt, but also very expensive.

### Security

When samples are collected to support a routine deposit analysis for mine planning, security is also important to prevent contamination or mislabeling. For government professionals conducting a due-diligence study or a validity examination, sample results often become evidence in court proceedings or contract negotiations. For a miner who is purchasing a property, taking the risk of mining a deposit based on misleading sample results may prove to be a poor investment that could result in bankruptcy. There is clearly great responsibility attached to evaluations; custody and control of the sample must be very strict, or the results may be valueless or misleading, if not fraudulent.

Proper custody and control means that the sample must be within physical control of the examiner until concentrates are delivered to a neutral third-party lab. Many geologists who are accustomed to examinations of lode deposits are familiar with the process; however, the larger size of a placer sample makes control and storage a challenge.

## Wash Plants and Sample Concentration

In order for a sample to be of any value, it must be reduced in volume to only the precious metals or commodities of interest. The wash plant is an assemblage of equipment that prepares the sample for separation and then removes the valuable minerals while allowing the waste material to flow out of the machine. There are a number of choices to be made regarding what equipment is to be put on the plant and in what order. The size of the plant and the feed rate are dictated by the type of placer deposit, lode source, sample size, and materials in the sample.

### Material Pretreatment

The ideal test plant contains a grizzly (figure 5.1) with 8- to 10-in spacing on the bars and a rock chute on one side. High-pressure water spray bars begin the initial cleaning of the pay material. Under the grizzly, a hopper with high-pressure spray water washes the material with direct discharge into a trommel.

The trommel is a combination of a screening and scrubbing unit. A trommel can handle nearly all types of samples, whereas a screen deck can be less effective in handling clay-rich material. The screen on the trommel should be gradational, with 3-in openings at the upper end and 1- to 2-in openings at the lower end. There should be a 6- to 8-ft scrubbing section preceding the screen section. The diameter of the trommel should be greater than 4 ft.

The screening section is needed to get the desired plant throughput, while the scrubbing section must be flat enough to retain the material until the clay is washed free. If the two are combined in one unit, the efficiency of both is often lost and the plant recovery will be less than designed (figure 5.2). An alternative method entails feeding from a hopper to a "washing trommel" and then to a screen deck for size classification. The aggregate industry has broken washing into separate processes for increased efficiency and throughput, but the placer industry has not made such a

Figure 5.1. The grizzly is constructed of 2-in x 4-in soft iron bars on 10-in spacing. Railroad rails are rarely used because they are brittle and will not stand the impacts from rocks and equipment.

move. The washing trommel can be adjusted to ensure that clean rocks are fed to the screen deck. Agitation of the gravel can be done with a number of units that have "bolt-on" wear component parts that decrease down-time for replacement. Rotational speeds and retention time can be tuned to the individual deposit characteristics.

Screen decks can also be matched to the deposit (figure 5.3). With careful testing, the screening system may be able to eliminate much of the waste material while concentrating the fraction that contains the valuable minerals. These multiple-deck screening systems can handle a broad diversity of size ranges and combinations. To further consolidate the system, the undersized fraction can be directed to a sand/gravel pump where the agitation of the pump completes the cleaning process before delivery to the concentrating system. The rubber-lined pump is exceptionally effective at dispersing clay with a minimal amount of wear on component parts. The oversize rock is carried away on an 18- to 24-in conveyor that is 15 to 30 ft long. A metal detector is mounted near the bottom of the conveyer so that any metal on the belt will trigger an alarm and shut down the plant. This prevents the loss of oversize gold to the coarse waste rock tailing pile.

## Concentrating Equipment

The grizzly/trommel/screen deck portion of the wash plant is used for cleaning the gold from the rocks and preparing the sample for volume reduction. The concentrating equipment that is used is the choice of the evaluator and is dictated by deposit conditions. Jigs or sluice boxes are the primary pieces of equipment commonly used on wash plants. Occasionally, the two are combined: the sluice box precedes the jig and recovers larger pieces of gold.

Figure 5.2. Components in a trommel screen system.

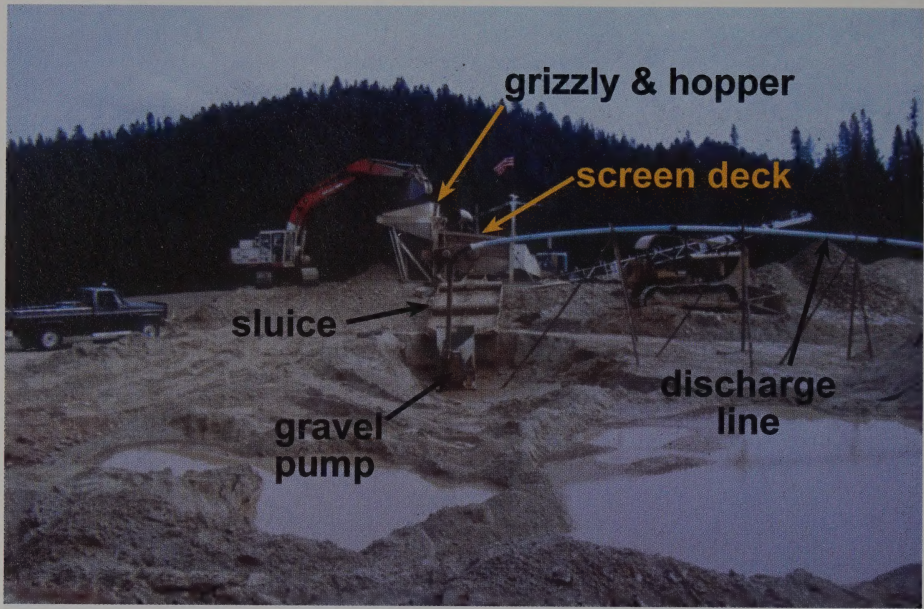

Figure 5.3. A placer wash plant utilizing a grizzly screen deck, waste conveyor, sluice, and gravel pump.

If fine-grained gold is present in the deposit, the evaluator may follow this equipment with a centrifugal recovery system such as a Knelson or Knudsen bowl (figure 5.4). These bowl systems collect gold particles that have a large surface area to weight ratio. These particles have a tendency to "swim" or remain in suspension like the clay or silt particles in the washing system.

It is important to be aware of the cost of recovery. If adding another piece of equipment costs $1.00 to recover a penny, the operator or evaluator probably did not need to add the recovery device. Operators can easily recover nearly all lag deposit gold particles by using a sluice or jig. Transport deposits may need further processing with a centrifugal concentrator. It is important to have indexed the cumulative particle weight distribution of the gold in the deposit. Each piece of concentrating equipment has an optimum size range of feed particles (figure 5.5). If the particles are larger or smaller than that range, it is unlikely that an economic recovery will be possible. Therefore, the plant should be designed to effectively cover the range of particle sizes that are important to the economics of each deposit. At the same time, a flow chart should be designed to emulate the production plant; this will ensure that the recovery rate of the test plant is reproducible at a full-production scale.

## Sluice Boxes

Sluice boxes are the simplest and most forgiving of all the concentrating systems (figure 5.6). They consist of an open-top metal channel with 10- to 12-in sides, the bottom width of which varies in increments of 12 in, depending on the feed rate. The optimum sluice box feed rate is 16 lcy/h/ft of width when utilizing angle iron riffles. The optimum water flow for this amount of feed is 384 gal/min/ft of width. Therefore, if processing 32 lcy/h of sand through a sluice, the sluice would need to be 2 ft wide

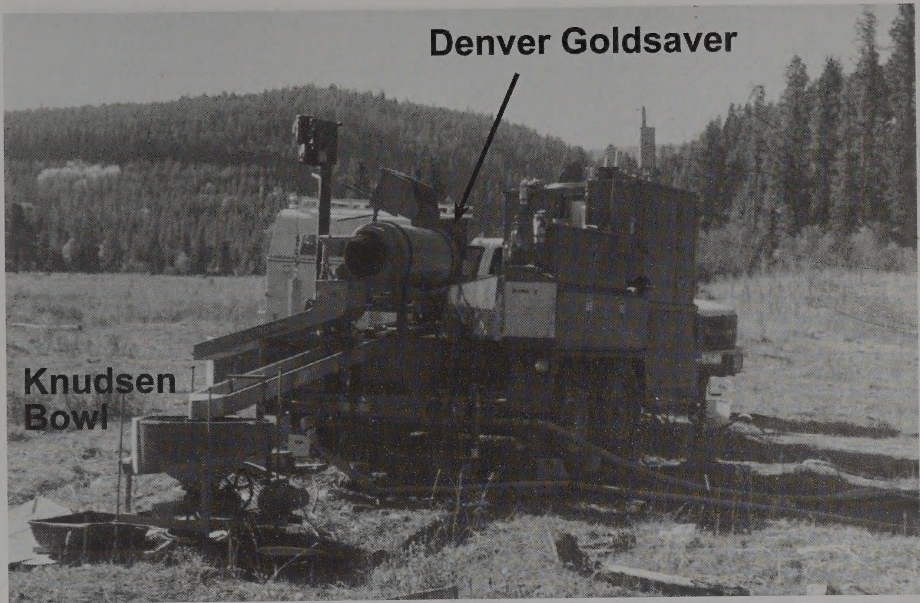


Figure 5.4. A small test plant facility is highly mobile but is labor-intensive. Typical capacity is only 1–2 yd³ per hour.

and would require 768 gal of water/min. If expanded metal riffles are used, the box width must be doubled for the same feed and water rates.

Because of the wide variety of particle sizes in placer samples, a test plant equipped with a sluice box should probably be designed with a 2-ft-wide sluice. Underfeeding, or starving, a sluice will have no effect; overfeeding, or slugging, the sluice will create gold losses. The length of the sluice should be at least 4 and as much as 8 ft. The riffle section should be made of 1-in by 1-in angle iron in 4-ft lengths and welded to 1-in metal strapping $^3/_{16}$-in thick on 2-in centers.

Each riffle (angle iron) should be tilted back about 15° (figure 5.7) toward the head end of the box. The riffle assembly should be about ¼ in narrower than the box. That space should be filled with either a ¼-in rubber strip on one side or two ⅛-in strips on either side. These are easy to install after cleaning and prevent sand from packing along the side of the riffle assembly. If the strips are retrieved first, the riffle assembly is easy to remove; if the riffle edges are packed in sand, they and the riffles will be difficult to remove and can be damaged in the process.

The floor of the sluice should be covered with Nomad® unbacked carpet or a similar product (Clarkson, 1992). This forms a gasket between the riffles and the sluice bottom and stops underflows that create gold loss. The riffle sections are normally held in place with wood or metal wedges.

To ensure high recovery of the entire range of gold particle sizes, it is important to alternate angle iron riffle sections with expanded metal sections composed of 4- to 6-lb/ft$^2$ expanded metal containing ¾- to $^7/_8$-in holes at 4-ft intervals (Clarkson, 1992). The pre-riffle section of the box should contain a 4-ft slick plate followed by a boil box that precedes a 2-in-high laminar-flow strip. The larger nuggets collect in the boil box behind the laminar-flow strip. Without this assembly, the water may not flow evenly over the riffles and this will diminish recovery.

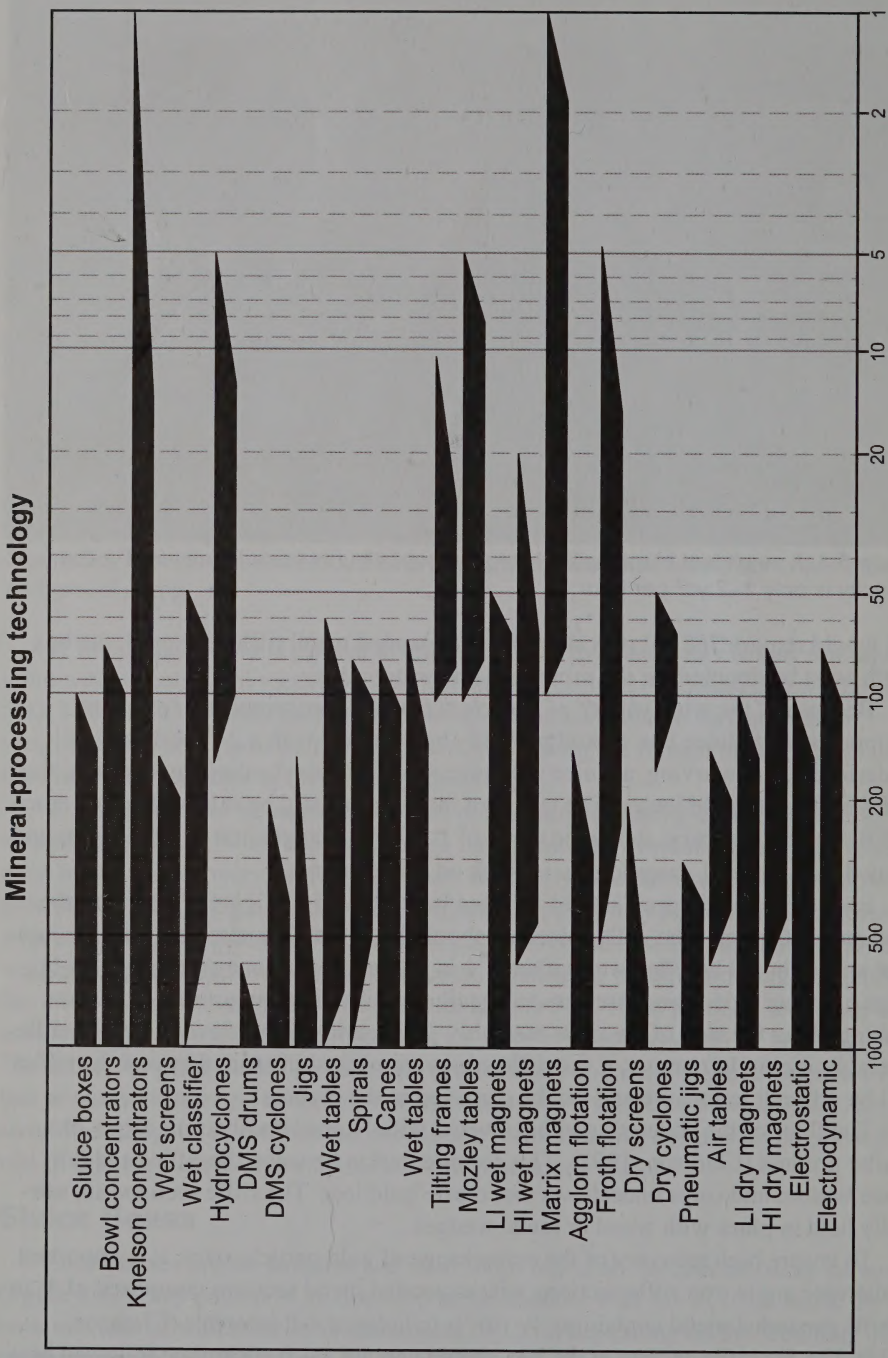


Figure 5.5. Effective range of application of conventional mineral-processing techniques.

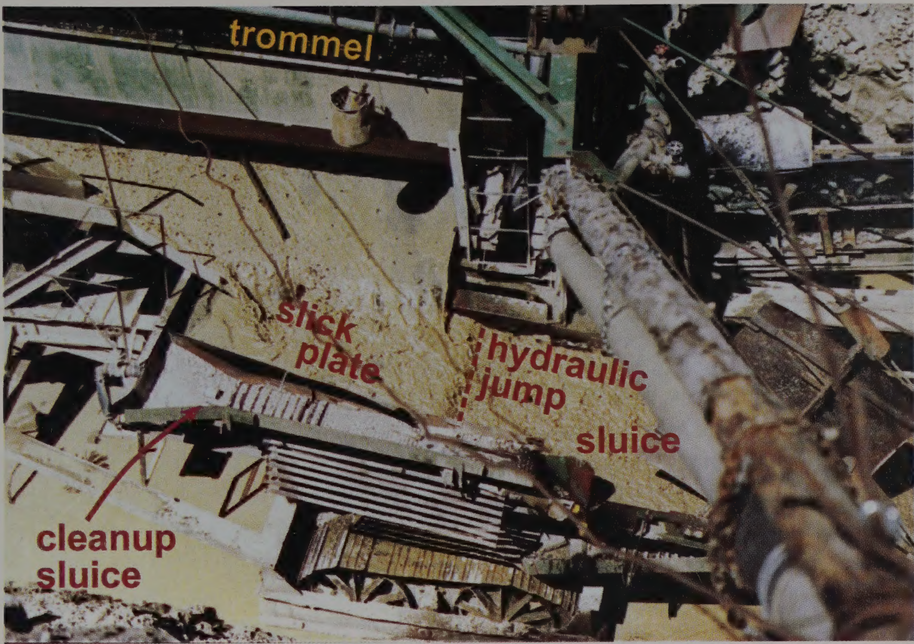

Figure 5.6. An operating wash plant utilizing a trommel feeding, a slick plate–sluice combination, and a hydraulic jump that creates a laminar feed for the sluice. The hydraulic jump also acts as a presettler for nuggets in this recovery system.

One option that works well is to collect the undersize trommel product in a gravel pump and pump to a sluice located above the trommel. This location will diminish unauthorized access to the gold, and the pump will further clean the product before it enters the sluice. With this layout, the plant can be built lower to the ground, but will still allow adequate room for sluice effluent discharge. The lower height of the grizzly will decrease the cycle time and increase throughput.

Cleanup is accomplished by removing the wedges, washing the riffle and screen assemblies, and collecting the sample concentrates. It is important not to lose any of the sample. Sloppy handling is inexcusable; by this point in the process each sample is very expensive.

## Jigs

Jigs tend to need more intense care and maintenance than sluices. Sluices can function with dirty, but not thick water (high percentage solids). Jigs work best with clean or only slightly turbid water. They also require a constant head pressure and a uniform feed delivery rate (figure 5.8). This can be accomplished by pumping the water to an elevated tank and allowing gravity discharge to the jigs.

To increase recovery, the jig bed ragging can be altered to match the gold particle size range. By adjusting the cam on the plunger, the frequency and length of stroke can be adjusted to maximize the recovery from the deposit. Whereas most gold is easily recovered with sluices, jigs are necessary in the recovery of sapphires and other gemstones because their specific gravity is so close to that of the waste material.

The jig hutch can be continually drained of solids while in operation to allow for fewer breaks in production. The jig beds are usually vacuumed in order to recover

nuggets or gemstones on a weekly or monthly basis. Efficiency is at its worst level when the operator fails to remove the material from the jig hutches. When allowed to fill, these become so tightly packed that they will not retain any more solids and recovery drops to zero. Jig units are best used in stationary plants where they can be kept level and properly adjusted. Deposits that contain high percentages of black sands, sulfides, or other heavy minerals are good candidates for the use of jigs, as a jig minimizes downtime required for cleanup.

Both jigs and sluices can recover milligram-size gold and heavier particles on a continuous basis with ease; however, smaller gold particles, particularly those that are thin and flat, can be difficult or impossible to recover with either. As shown in Table 5.1, every gravity concentration system is designed to provide optimum recovery of material within a specific size and density range. Each type of equipment comes in many sizes and models, so care must be taken to match the proper plant components to the mined material's size range and specific gravity.

Table 5.1 provides general parameters for several common types of gravity concentrating equipment, but individual tests of the feed material and equipment size should be conducted to determine effectiveness. Because of the difficulty of thorough cleaning between samples, jigs are often a poor choice for most phases of sampling.

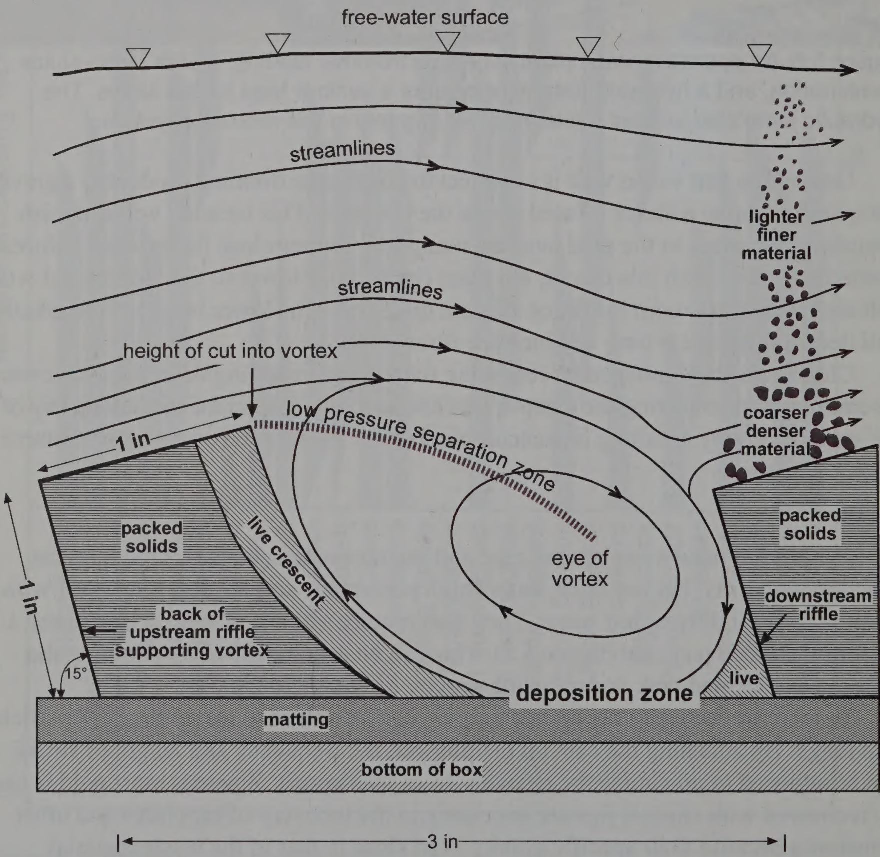


Figure 5.7. Detailed cross section of a sluice-box riffle recovery mechanism (Clarkson, 1991).

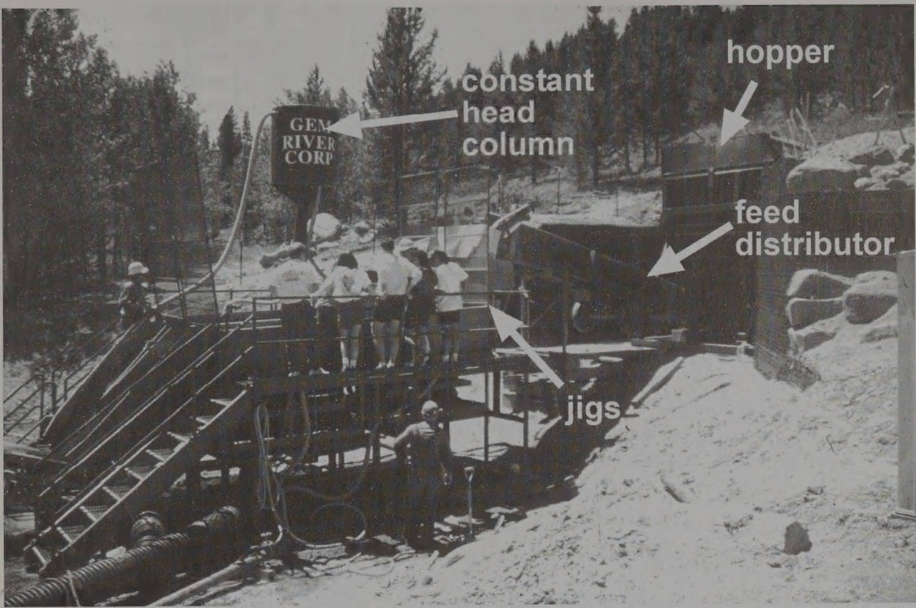

Figure 5.8. This Gem River Corp. jig plant (Dry Cottonwood Creek, Powell Co., Montana) utilizes a washed and sized feed stock from a screening plant in the mine pit. The constant head column maintains constant pressure in the jigs to increase recovery rates.

They may have greater applicability in a pilot plant phase or in a fully operational mine.

If additional concentrating equipment is designed to follow a sluice or jig, then the waste material from the primary concentrators must be pre-screened to the correct size for the subsequent equipment. It might be easier to initially screen the feed into two sizes, but in that case the secondary recovery becomes a primary system, and there still is no backup system to recover the values missed by the primary equipment.

Of the equipment shown in table 5.1, only the bowls and Knelson hydrostatic concentrators are commonly used as backup systems. The spirals and shaking tables are most commonly part of a cleanup circuit and are rarely used as a portion of the primary placer concentration system.

## Centrifugal Concentrating Systems

For the small, thin gold particles that can be common in alluvial (transport) deposits, the Knudsen Bowl and Knelson concentrators may be used as either primary or secondary recovery systems. These units spin the slurry and accentuate the settling characteristics of the higher specific gravity materials. The heavy minerals are concentrated in the units, where they are cleaned in batch runs, and the waste material flows through the system and is discarded. The frequency of cleaning is a function of the feed rate and the heavy mineral concentration in the feed material. It is imperative that examiners consider every sample deposit by screen analysis to determine the percentage of each of the various size fraction's gold particle size intervals and the amounts in each range. When that information is known, a wash plant can be designed to match the deposit.

Table 5.1 Gravity concentration operating criteria

| Equipment | Optimum feed size range | Feed requirements | Water capacity |
|---|---|---|---|
| Jigs | -½ in to 150 mesh | 1.2 $yd^3/ft^2$ of bed/h | 3–8 $gpm/ft^2$ |
| Sluice (angle iron)<br>(expanded metal) | -2 in to 400 mesh<br>-1 in to 400 mesh | 16 $yd^3$ lcy/ft of width/h<br>8 $yd^3$ lcy/ft of width/h | 384 gpm/ft width<br>192 gpm/ft width |
| Shaking table | -14 to 35 mesh | 0.5–2 tons/h | 18–72.3 gpm (10–15 percent solids) |
| Spirals | -10 to 325 mesh | 1–2 tons/h | 22–28 gpm/unit (25–35% solids) |
| Knelson hydrostatic concentrator | -¼ in to 500 mesh | 0.6 –1100 tons/h | 5–550 gpm |
| Bowl concentrator (Knudsen or Ainlay) | -⅛ in to 500 mesh | ½–2 $yd^3$/h | 25–40 gpm |

### Spirals

The first spiral was invented in 1942 by I.B. Humphreys. The system's best selling point is its lack of moving parts. The sized slurry is fed into a cast-iron spiral unit (figure 5.9), where lighter material (waste) travels to the outer edge of the spiral and heavy minerals remain near the bottom of the trough. The waste is allowed to pass through while the heavy minerals are collected for further processing. Each unit is built with a varying pitch and radius to optimize recovery. Although most sand-size material can be processed through one or two models, higher recovery rates are accomplished by matching the deposit's particular mineral characteristics to the optimum recovery equipment.

Because of the low feed rate per machine and the need for rougher and finish spirals, it is often necessary for miners to construct a large facility with many units. These units are used in primary recovery systems where the product is small (like zircons) but is in large volumes that might plug a sluice. The units could be effective in transport-type deposits formed from sulfide-rich lode sources. Most applications require the plant to be stationary with a steady feed rate. These units are not often used in placer operations because of the high unit cost and low feed rate per unit.

## Plant Size

The design of wash plants must be dictated by the lode source. Many beach deposits are high in chromite and magnetite; some skarn deposits contain large amounts of magnetite. Both require concentrating systems, such as jigs, with large concentrate storage capacities. The minimum plant size is dictated by the sample volume to be processed; this, in turn, is influenced by the nature of the lode source and deposit characteristics, as well as the availability of suitable equipment to feed the material to the plant.

A drill sample could realistically be concentrated by a rocker or even by panning; however, as the sample size increases, so does the need for larger capacity equipment or even a production wash plant. Channel samples from underground drifts or trenches can be easily handled with a small, self-contained trommel (figure 5.2) and sluice or a

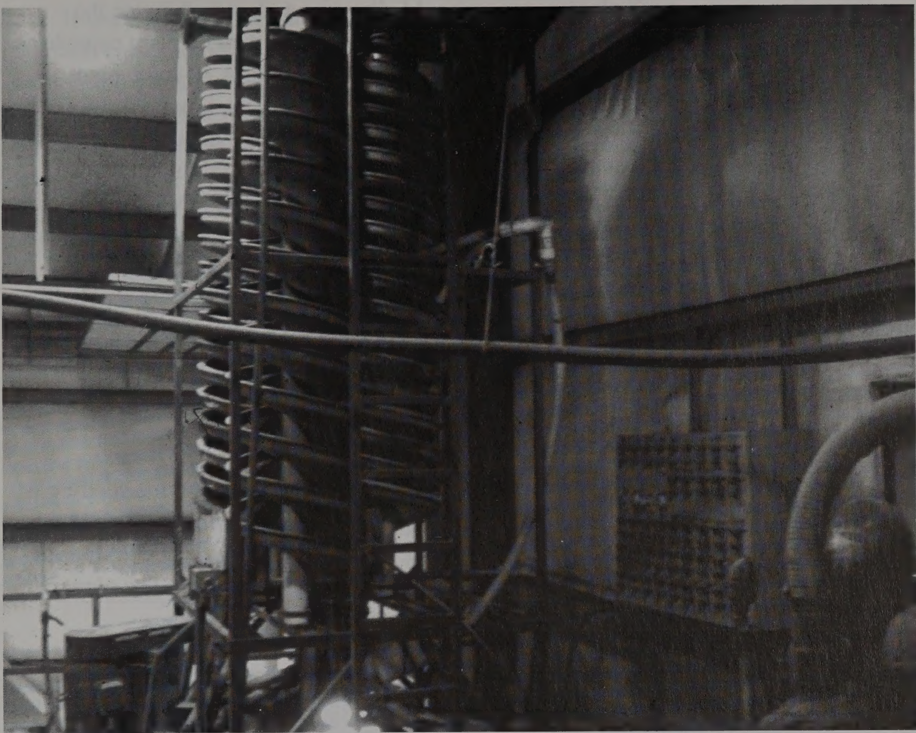

Figure 5.9. This spiral plant used at Madison Milling (Virginia City, Montana) concentrates small gold flakes in a mill recovery system.

vibrating screen and sluice. Most of these small units have a capacity of 1 to 2 $yd^3/h$. These machines can quite effectively handle samples of 1 lcy or less. They screen the sample to about -3 in. in a small trommel and concentrate the fines in an oscillating riffle tray. They are easy to clean, and it is nearly impossible to lose the valuable concentrate fraction because the system allows maximum control by the operator.

A few companies make a mobile vibrating sluice box in a “high banker” (figure 5.10) category that is effective for use on remote sites and, with some riffle modification, for processing 1-lcy or smaller samples. Although field tests have shown these to be less durable than trommel units under extended-use conditions, the mobility offered by their design is still an advantage. These units screen the material to about 3 in and concentrate the fines in a sluice box.

As the sample size increases, it becomes difficult to maintain reasonable process times, both with the use of mechanized digging equipment and with hand-dug shafts. Because of labor costs, the time associated with processing samples through a small plant may become more costly than the expense of obtaining a larger wash plant. The smaller units lack sufficient storage for concentrates where larger quantities of heavy minerals are encountered and retained in the sample concentrates. Deposits containing 20 percent or more of black sand are common, and the plant typically must be able to store 5 to 20 percent of the sample in the riffles of the sluice or jig hutch, which is difficult for a small machine. If the plant is too small and samples measure 1 $yd^3$ or larger, multiple cleanups per sample may be necessary in order to maintain quality results.

When designing a wash plant, a miner should allow for a plant with twice the hourly capacity of at least double the anticipated sample size. A generic plant capable of processing bulk samples should have a capacity of 15 to 25 lcy/h. A 10-lcy/h plant would probably be the smallest advisable for sampling lag deposits; however, transport deposits most likely can be processed with smaller plants. Since lag deposits also consistently contain larger rocks, the durability provided by increased metal thickness in a larger plant should be considered during the selection of a plant size. A steady feed of 6-in-diameter boulders will rapidly destroy many of the lighter commercial wash plants.

The grizzly and hopper should be large enough to handle direct feed from the excavation equipment. The hopper size needed for an excavator bucket is much different than that needed for a wheel loader or tractor/backhoe combination. These hoppers should be oversized by a factor of at least 10 percent for minimum sample loss from spillage.

## Plant Feed Rate

Losses in the wash plant are either from spillage or from periodic overfeeding of the plant (slugging). The process capacity is designed for an assumed steady feed rate. A 60-lcy/h plant should process 1 lcy/min. However, if the excavator bucket is filled every 45 s, a feed rate of 1 lcy/15 s results, which is an impossible rate. The plant cannot accept the material and process it in that amount of time.

Figure 5.10. Small field test plant, designed and constructed by Goldfield Engineering and Machine Works, called a Prospector II. It is highly mobile and has a capacity of about 1 yd³ per hour under ideal conditions. Process rates are less in difficult material such as clay-rich gravels.

If the plant can only process 1 lcy/min, the actual process rate of a 60-lcy/h plant is much closer to between 30 and 40 lcy/h because a steady feed rate cannot be maintained. It is possible to use a conveyor belt feed system that has a steady discharge rate but tolerates surging feed rates, which will then utilize the full potential of the plant. Although this can work, the non-homogeneity of the feed material usually dictates oversizing the plant by 80 to 100 percent.

While direct feeding the plant, it is important that the wash plant operator guides the excavator operator in order to not exceed the optimum feed rate. The wash plant operator monitors potential plugging of the grizzly, quality of rock washing, effectiveness of the screens, blockages of the screens, and performance of the concentration equipment.

## Cleaning the Plant

After each sample has been fed, the entire plant must be inspected and cleaned in order to prevent contamination of samples that follow. The grizzly and hopper, along with the feeder bucket of the excavation equipment, must be cleaned of all fines and clay. If the trommel cannot be easily emptied, at least a visual inspection should be performed to ensure that no nuggets are trapped. Extra time spent at this stage is a good investment compared to decisions based on erroneous information.

# Concentrates

After the sample has been run, the volume has typically been reduced substantially. A 5-yd$^3$ sample may only yield 70 to 80 lbs of concentrate. This is collected in a tub or bucket for further concentration. It is advisable to screen the concentrate to about 3 in, and the +3-in material remaining on the screen must be carefully examined for valuable material. Gold nuggets (or gemstones) must be picked out and added to the fine fraction (-3 in) for further processing. If the deposit is known to contain scheelite, the waste must be viewed with a black light in a dark environment to verify the presence of gold and ensure that losses are kept to a minimum. It may be advisable to save all of the solid waste products from the concentrates until a determination is made on the property. Storage and review of sample waste are much cheaper than resampling.

The -3-in product should be panned to reduce the volume and to allow for limited field inspection. The concentrate products from each sample should be dewatered and placed in a heavy plastic bag. This bag should then be properly labeled and placed in a second bag for safety. Finally, all of the sample products should be placed in a plastic bucket that can be sealed for transport and security. The concentrate products need to be processed at a site where continued security can be assured. While in the field, this may be a tent or garage, but the preferred location is a proper laboratory facility capable of accommodating a complete and secure sample analysis.

The field concentrates must be processed in an orderly fashion (figure 5.11). They should be weighed at the beginning of the analysis. The results from this weighing are used to determine concentration rates and process capacities necessary for the processing equipment. The concentrate from the field must be wet-screened with a 14-mesh sieve. The +14-mesh product needs to be examined under a microscope for valuable minerals. Careful notes should be taken, including mineral types (appendix B), gold and mineral textures, and any unusual observations. Visual estimates of the

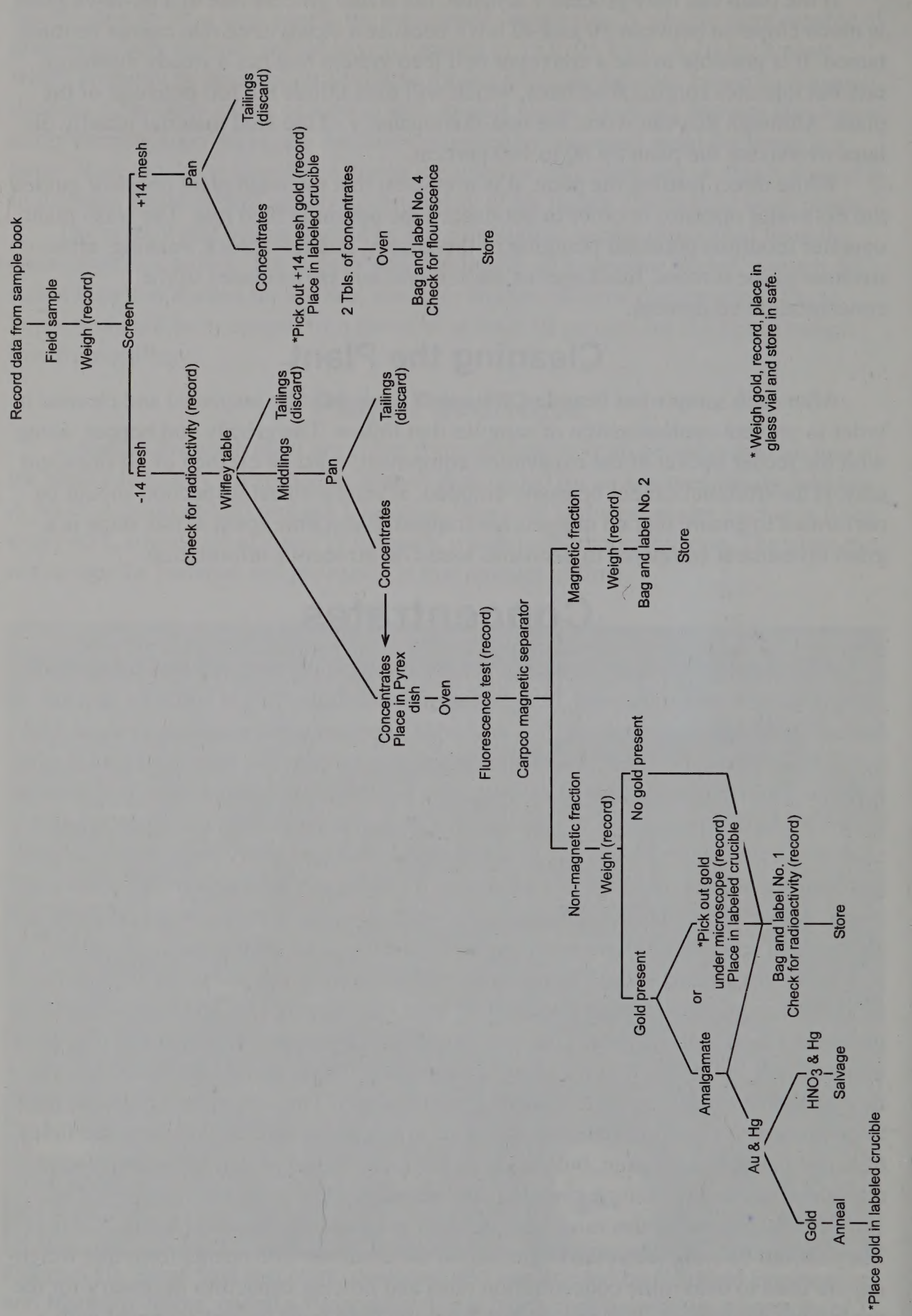


Figure 5.11. Placer lab-procedure flow chart (U.S. Bureau of Mines, Western Field Operations Center).

volume percentage of each mineral should also be recorded. In some cases, mineral examiners working on critical data should take photomicrographs for a visual record. All products must be bagged and stored. Any coarse gold should be picked out, weighed, and stored in a vial for future reference. The evaluator should note physical characteristics of the gold particles—such as shape, color, and textures—in the notes and look for similarity between gold specimens of different samples. Deposits may contain gold specimens with more than one set of characteristics; however, if the characteristics change radically, there is cause to be concerned about salting. If one or two sites are drastically different in grade and appearance from the others, resampling and closer scrutiny may be warranted.

Figures 5.12 through 5.16 show some of the variety of gold specimen characteristics. The fine-textured gold shown in figure 5.12, in which each particle is more like gold foil than other more massive, three-dimensional specimens, would probably come from a transport-type placer.

Some deposits produce wire gold and, more rarely, gold crystals (figure 5.13). Delicate gold does not travel well in gravel and tends to break up or become deformed. Examples of this kind are likely to be found near the lode source.

Figure 5.14 shows gold particles that exhibit casts of the crystals of gangue minerals from which the gold was liberated. Like wire gold, the delicate edges would not remain undamaged for any significant distance during transport; the lode source should be located nearby. Similar conditions apply to the gold shown in figure 5.15. Gold crystals occur in only a few mining districts. If placer gold particles do not exhibit folding and impact damage from rolling rocks, this is an indication that they remained near the source.

Figure 5.16 shows the comparison between flat and angular particles. The flat piece which has not been folded has probably not traveled far. The grainy texture may be developed by the leaching of silver exposed on the surface. High-purity (900+ fine) particles are usually much smoother and rarely exhibit pitting. Under close inspection, the contrasting angular pieces contain casts of crystal faces of gangue minerals from which the gold was liberated during degradation.

Gold also occurs in various colors and lusters (figure 5.17). Manganese may stain it black, copper will turn it brown or green, and mercury may make it appear silver. Some residual compounds may coat the gold specimen and make it appear dull or earthy. The coatings may disguise the gold, but they do not change the specimen's weight significantly. Scratching or cutting the specimen will reveal its hidden character. When analyzing concentrates, evaluators should make no pre-judgments on any high-density heavy particle until all of the possible tests have been administered.

Figure 5.18 shows the radical contrast between black or gray gold and bright, normally colored gold, both found near Placer Dome's Golden Sunlight Mine in Whitehall, Montana. Cutting or scratching the manganese–copper coatings reveals gold that shines as brightly as the smaller, uncoated pieces. The specimen shown in figure 5.19 is manganese-coated gold from McKormic Creek near Missoula, Montana. Note the bright gold color where the coating has been scratched. All heavy material in a pan must be inspected closely before being discarded. Some districts in Africa have no gold-colored gold. Silver, black, green, gray, tan, brown, and red are among the most common colors of coatings. Gold with these coatings will not amalgamate. Often the concentrates must be abraded with mill balls prior to further attempts at recovery.

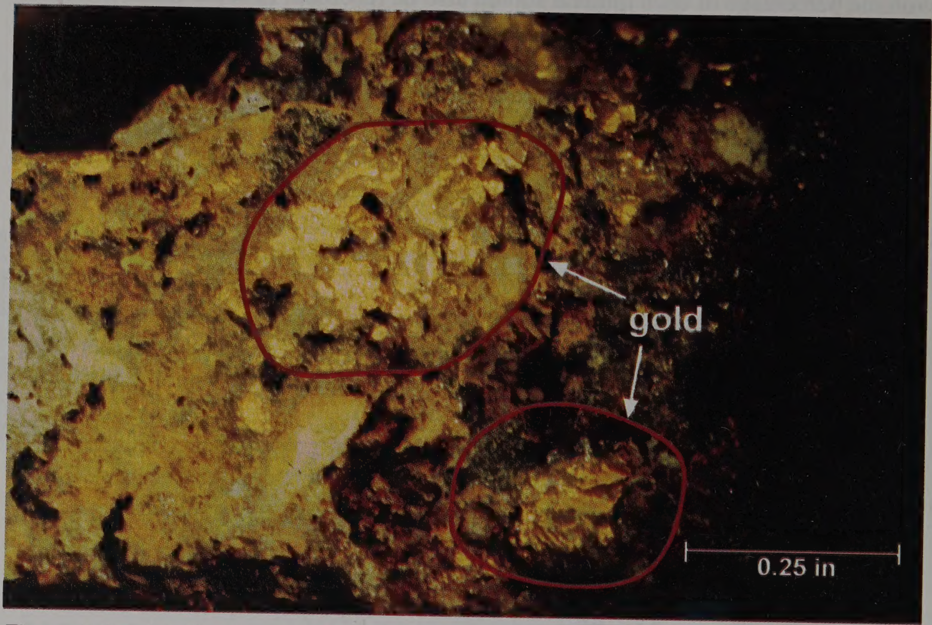

Figure 5.12. Small gold particles in a lode sample. Note that the gold tends to form in the voids between crystals of gangue minerals.

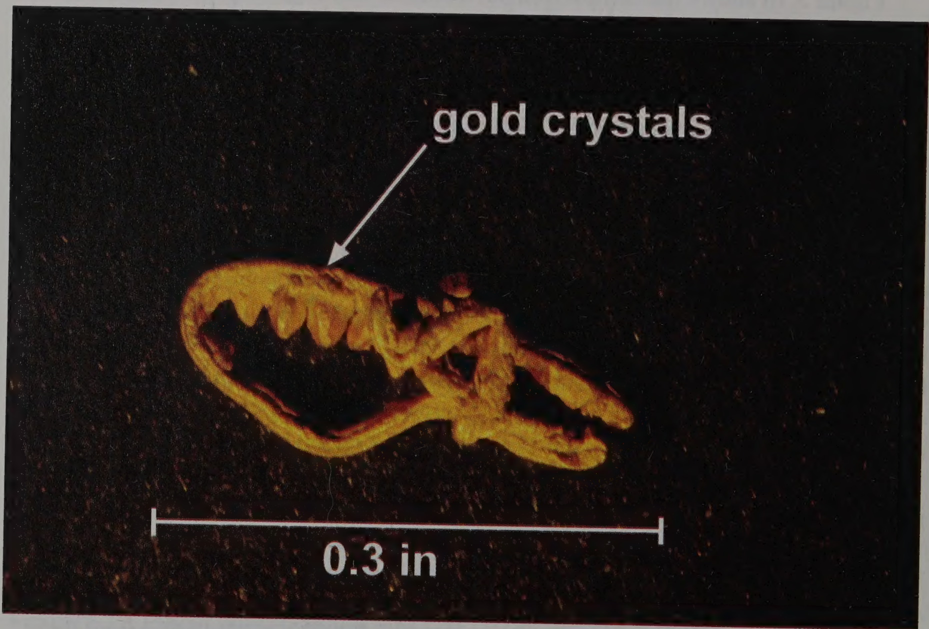

Figure 5.13. Wire gold and gold crystals (rarely seen) do not last long in the placer environment. They are a good indicator of a possible residual deposit.

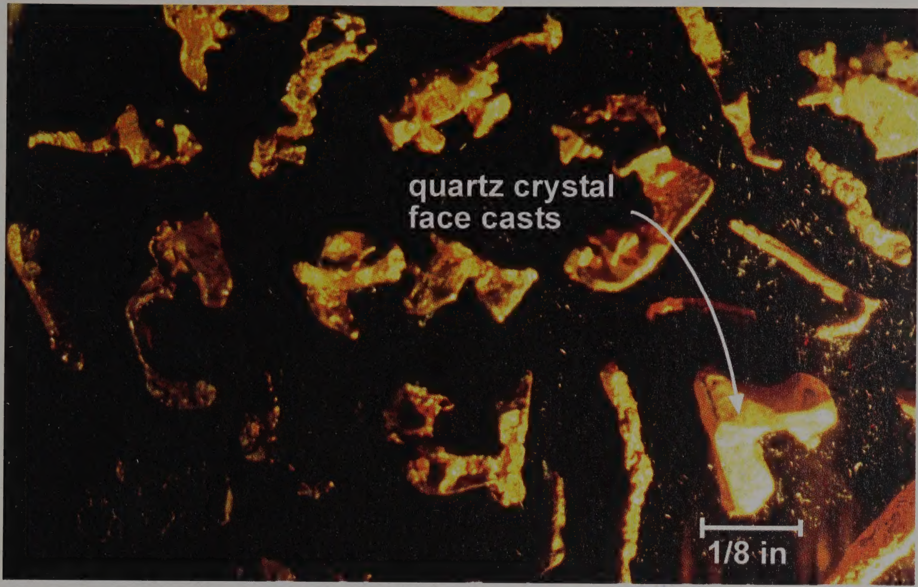

Figure 5.14. When gold forms around crystals of gangue mineral and then is liberated, the faces of the crystals are often imprinted on the gold. Sharp edges are good indicators of short transport distances.

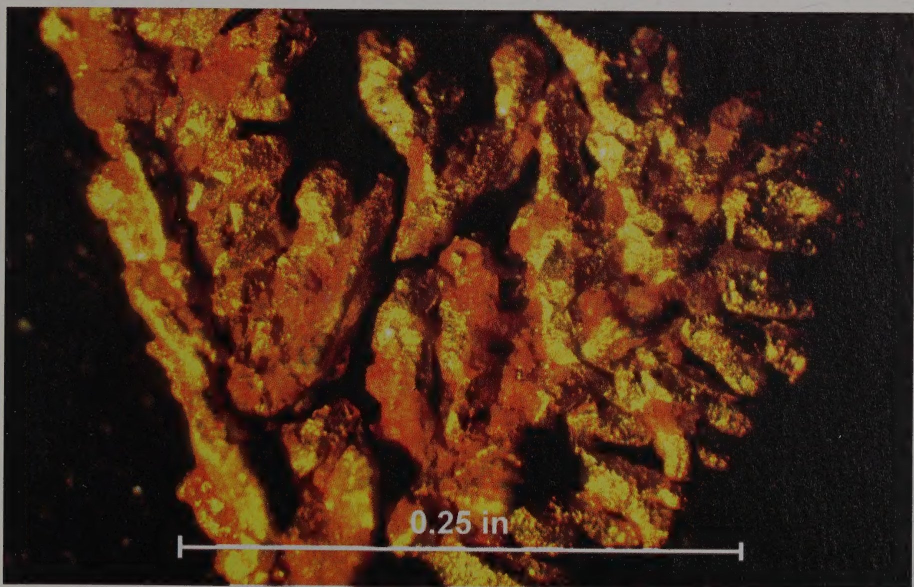

Figure 5.15. Gold dendrites or crystals are beautiful but rare, and are destroyed by transport. They are often unique to specific locations. These are from near Blewett Pass, Washington.

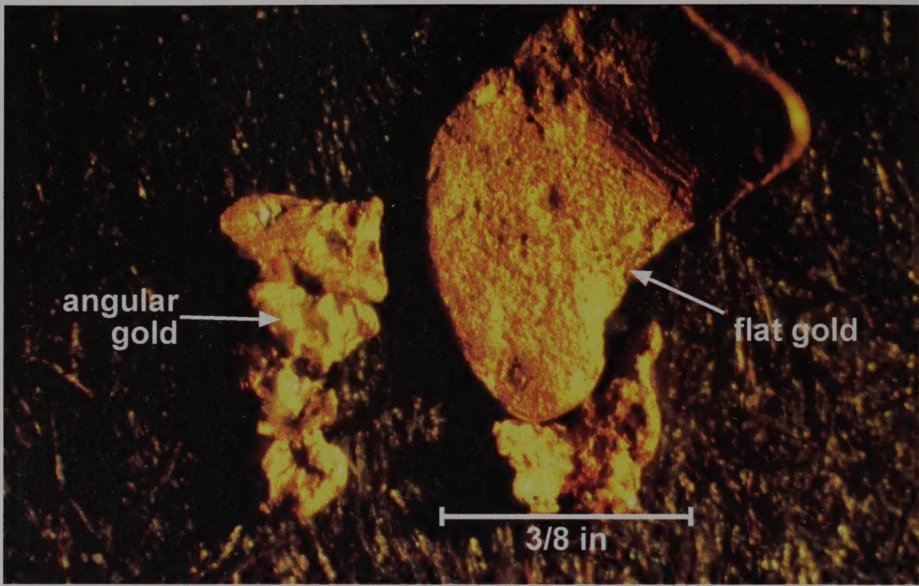


Figure 5.16. Flat gold may be a product of fluvial transportation or it may have formed in a smooth crack in a rock. Angular gold often forms at the same time or after other gangue minerals are formed. The texture reflects voids or irregularities in the host rock.

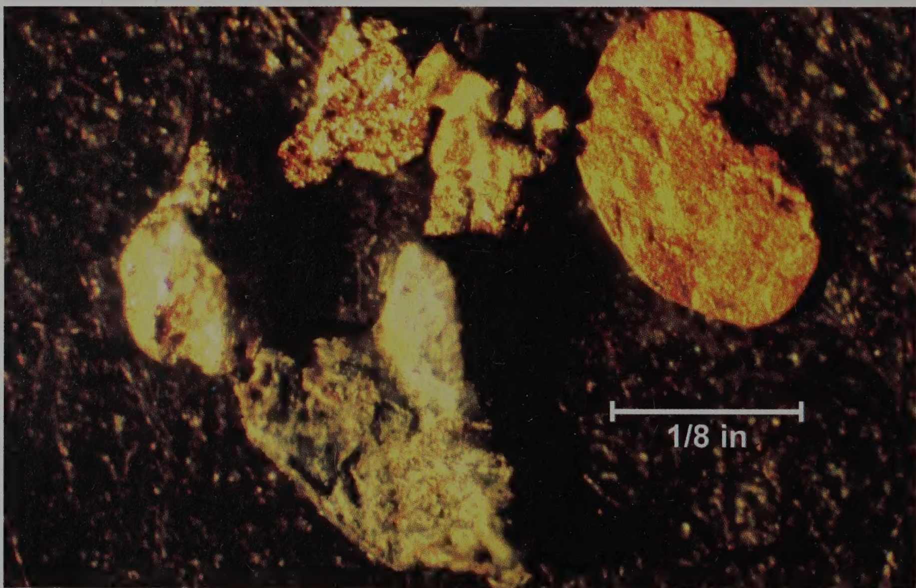


Figure 5.17. Gold comes in a broad variety of colors and textures. Some colors are from surface stains, while others indicate alloys with metals such as copper and silver.

As shown in figure 5.20, gold that has been naturally amalgamated has distinct characteristics. It is common to see naturally amalgamated specimens in most placers, especially those formed from an epithermal lode source where mercury is a common accessory mineral. The mercury dissolves the gold surface during amalgamation. The color of the coating indicates the amount of mercury residue on the specimen: the darker the color, the more residue. When the mercury is removed, gold microcrystals are formed on the surface, which gives the specimen a bumpy sandpaper texture. Although this is a common occurrence, if all of the gold in the sample looks like this, the evaluator should be concerned about possible salting.

After the coating is completely removed, the -14-mesh product can be further concentrated. If a commercial shaking table is available, the sample may be quickly concentrated. If not, careful panning will achieve the same goal.

Once the sample has been concentrated to the evaluator's satisfaction, the heavy mineral volume can be determined. If large amounts of black sand (magnetite, ilmenite, garnets, etc.) are present, it may be necessary to dry the concentrate and remove the magnetic fraction with a sealed magnet or commercial magnetic processor. It is imperative that the operators visually inspect the magnetite to ensure that no gold was removed with it.

The magnetite should be weighed, labeled, and stored like the other concentrates. The remaining product must be evaluated by visual identification of the accessory minerals, gold, or other valuable minerals. This information will help verify results if the sample is sent to a laboratory for processing. If gold or gemstones exist in the sample and the accessory minerals are not too plentiful, the evaluator may want to view the sample under a microscope and hand-select the specimens using non-magnetic, surgical tweezers. Each sample should then be stored in individual specimen bottles.

## Amalgamation

If the sample contains fine gold (microscopic particles) that cannot be efficiently removed by hand, the entire sample should be amalgamated with mercury. If the gold particles are coated with iron or manganese, the evaluator can clean the sample by first turning it in a smooth-walled amalgamation drum with two ceramic mill balls until the gold surfaces are bright and shiny, then removing the balls and rinsing the sample before amalgamating. It is important that the concentrates are not split for amalgamation and that they are amalgamated in their entirety. Results of the amalgamation should be reported in total milligrams of recovered gold and silver.

**Caution: Mercury, like many other substances, can be hazardous if used incorrectly. Be sure to receive proper instruction for safe handling and disposal. Always comply with local laws and restrictions.**

The cleaned sample should be replaced in the drum, and the drum should be filled with water. The process of amalgamation consists of placing a bead of mercury, about ¼ to ⅜ in., in a parting cup and barely covering it with distilled water. Two to three drops of a 1:1 nitric acid solution should be dropped onto the mercury until the surface begins to bubble. The cup should then be lowered into the drum and tipped on its side so the mercury bead can roll onto the sample. It is imperative that the mercury is always placed gently into the drum and never allowed to fall; if it falls, it will shatter into tiny balls that have such high surface tension they will never rejoin or adhere to the gold. The sample should be covered with water and the drum turned at 2 to 3

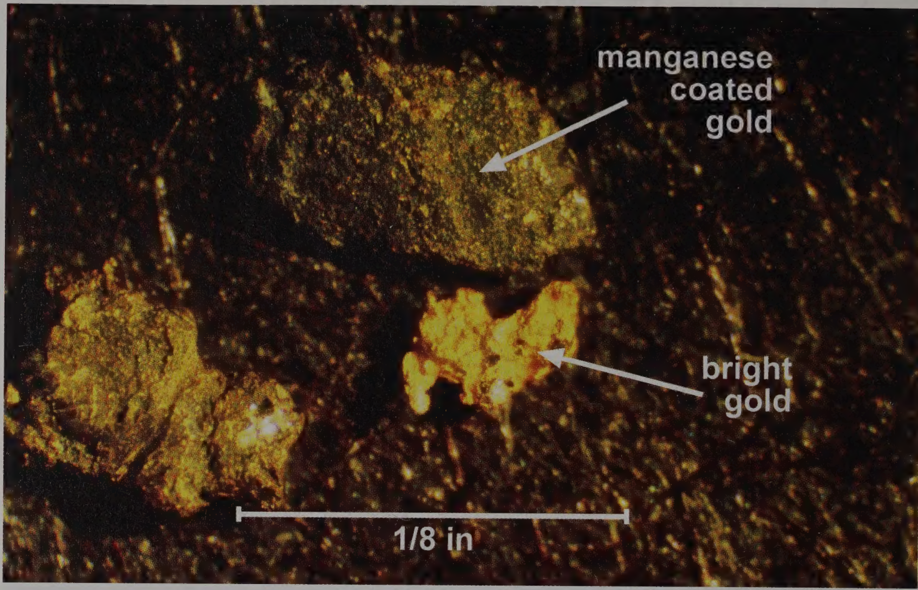


Figure 5.18. Gold found in placers near the Golden Sunlight Mine (Jefferson Co., Montana). Manganese-coated gold may be black or brown and will not amalgamate with mercury. Bright gold may indicate high silver values and may be worth less. Although colors are misleading, both types have high density and can be panned.

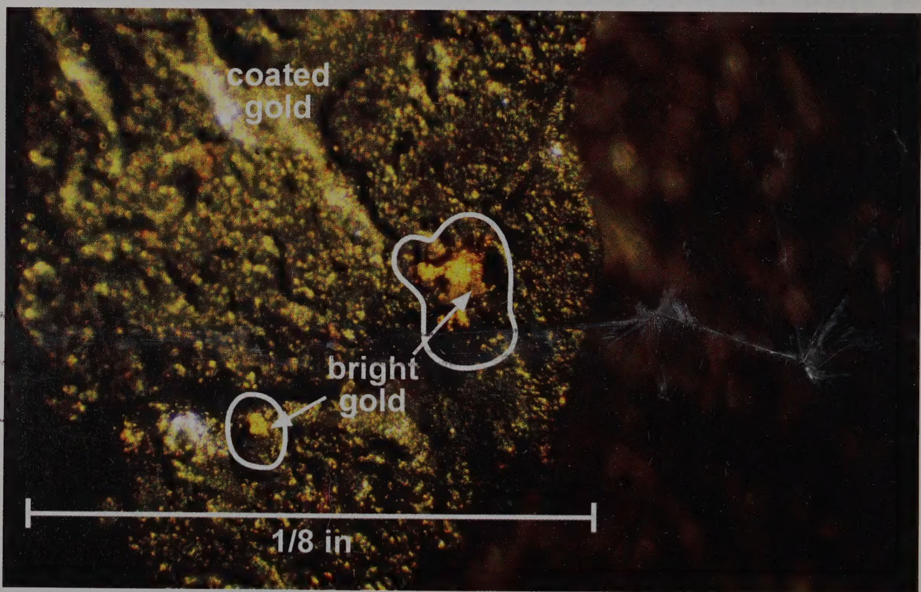


Figure 5.19. Gold coated with manganese (McKormic Creek, Missoula Co., Montana). If the coated gold is closely inspected, small areas of uncoated gold may be observed. Once isolated under a microscope, the gold can be cut or scraped with a knife to reveal its true colors.

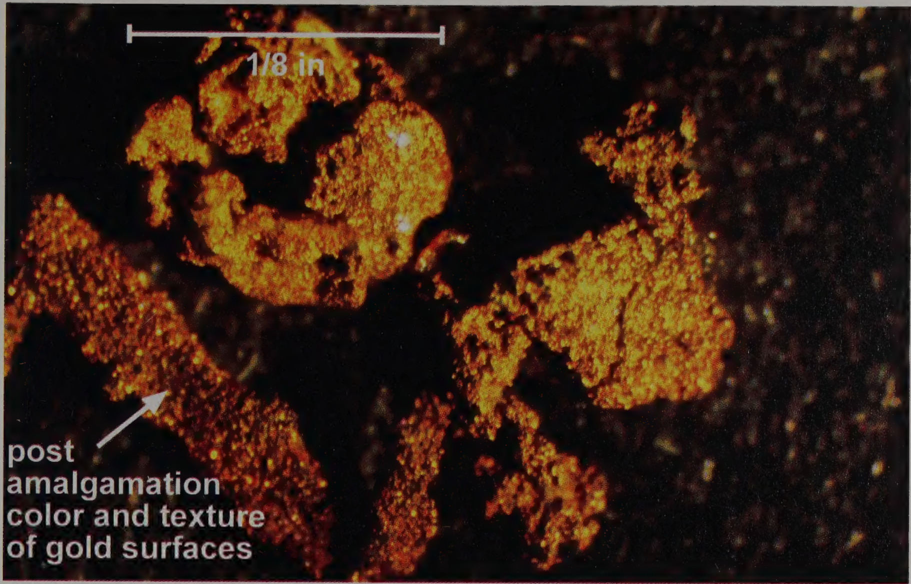

Figure 5.20. After gold is amalgamated and annealed, it has a distinct color and texture. The mercury dissolves the surface during amalgamation, but when the mercury is dissolved with nitric acid, the gold precipitates on the surface of the gold particle core in the form of microcrystals. This leaves a rough, textured surface. If the gold is left in mercury for a long time, it will precipitate out in long needles.

rpm for roughly 1 h. During this process, the drum should be inclined at 15° to 45° to position the gold and mercury together in the bottom of the drum.

At the completion of the process, the amalgamated sample should be discharged carefully into a glass pie plate. The gold and mercury sponge bead will now resemble gray solder, and gold may be seen on the surface of the bead when it is viewed through a microscope. If insufficient amounts of mercury were used, it may look like a gray paste and free gold will remain in the sample. By panning carefully, the amalgam ball(s) may be isolated in the plate where it can be picked up with an eyedropper or the tweezers and placed in the parting cup. The remaining sample should be checked carefully for gold and mercury. If none is found, the sample should be dried for further testing.

The amalgam sponge should be placed in a parting cup, covered with approximately 40 ml of 1:1 nitric acid solution, and set on a heating unit at a low heat. This unit should have a fume hood for safety. Proper safety clothing, including glasses and gloves, must be worn. The sponge will begin to bubble and then will give off observable brown vapors as the bubbling becomes more violent. If needed, a few drops of distilled water can be placed in the parting cup to slow the reaction and aid observation. Be careful to not breathe the fumes.

When the reaction is complete, the bubbling will cease, and a brown lump (or flakes) will remain in the crucible. The spent acid solution should be decanted into a plastic bottle and enough fresh 1:1 nitric acid solution added to the parting cup to cover the sponge material. Again, when the reaction stops, the sponge material should be rinsed three to five times with distilled water. Each time, the rinse needs to be discarded to a plastic bottle marked "spent solution." At the end of the final rinse, as

much water as possible should be decanted from the crucible and one to two drops of rubbing alcohol (isopropyl) added.

Next the crucible can be placed on the heating unit and covered. This allows the water to evaporate without blowing the gold out when the last drop of water evaporates. When the evaporation is completed, the gold will be dry. If the sample was not rinsed well enough, it will be glued with a greenish black asphalt-like material to the crucible; if this is the case, add 1:1 nitric acid solution when the crucible is cool and start the process over.

The gold will now be brown and will still have some mercury coating it. At this point, it should be annealed or roasted. The crucible should be placed on a ring stand positioned above a propane torch or Bunsen burner until the crucible glows cherry red for 10 to 15 min. Again, this must be done under a fume hood while wearing the proper safety equipment, or at the very least with very good ventilation. As an alternative, concentrate can be sent to a commercial lab for processing.

To calculate the amount of gold recovered for the entire sample, add the final product to the specimen gold (large mesh sizes) previously collected and weighed.

The dried sand or remaining concentrates should be checked with a black light for valuable accessory minerals such as zircon and scheelite. Visual estimates of the amount found should be recorded. The material can also be checked for radioactive and rare-earth minerals and then weighed, labeled, and stored until the completion of the project.

If the samples are sent out for amalgamation, the entire sample must be returned along with the results. Each sample must be visually inspected before shipping and upon receipt back from the lab to verify that the same samples were returned, and to check the completeness of the amalgamation process. Finally, each sample should be carefully panned and examined under a microscope to verify that no gold, mercury, or amalgam remains.

The bottle of spent mercuric nitrate solution should be stored until a gallon has been collected; then place this container of solution in the fume hood with the lid off and add copper shavings carefully. The mercury will precipitate out for reuse, and the remaining copper nitrate solution should be disposed of following the proper guidelines.

## Fire Assay

It is imperative that the process of fire assaying is never considered as a viable means of evaluating a placer deposit. It may be used to evaluate gold contained within magnetite or pyrite in the concentrates; it must not be used until the free gold is removed. The amalgamation process duplicates production techniques and represents what will be recovered during mining. Any destructive technique, such as leaching or fire assay, will generate an inaccurate result. These techniques will report the total gold contained, but not necessarily the recoverable gold.

The fire assay technique has an additional error built into it. The free gold in the placer sample creates a nugget effect that cannot be overcome. The gold will

not grind fine enough to make the sample homogeneous. Because only 30 g (approximately) per sample is utilized, the result will represent a sample of a concentrate as opposed to the whole deposit. Because of the nugget effect, only the no-gold samples will be comparable. The rest will represent a high-value concentrate.

The practice of reporting fire assay results of concentrates is commonly used in scams and mining investment frauds. The technique will almost always portray the placer as extremely rich. Any gold placer analysis results reported in troy ounces per ton should immediately be suspect. Other scams and frauds use secret analysis methods that are proprietary. The proponent will usually state that conventional methods will not detect the gold.

# Reporting

All data should be consolidated on a single form (table 5.2; see page 172), which includes sample site, sample interval, sample number, volume represented, sample description, gold weight recovered, grams per cubic yard of sample, amount of magnetite (pounds per sample), concentrate weight, pounds of concentrate per bcy, and amounts of radioactive or fluorescent minerals.

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**Table 5.2 Sample Datasheet**

## PLACER SAMPLE EVALUATION

Site No. ________ Project: ______________________________
Sample No. ________ Location: ______________________________
Year: ______________ Initials: ______________

| Sample No. | Sample Interval (ft) From | Sample Interval (ft) To | Gold Weight (mg) | Sample Volume (ft³) | Sample Concentrate Weight (lbs) | Observed Gold (colors) +14 mesh | Observed Gold (colors) -14 mesh | Gold Value ($/yd³) (@ $/Troy Oz.) | Gold Fineness | Black Sand (lbs/yd³) | Black Sand Magnetic Fraction % | Gold Assay Results | Flourescent | Radioactivity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | 1 |
| | | | | | | | | | | | | | | | 2 |
| | | | | | | | | | | | | | | | 3 |
| | | | | | | | | | | | | | | | 4 |
| | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | 6 |

## CONCENTRATE INFORMATION

| Magnetic Friction (gms) | Nonmagnetic Fraction (gms) | Black Sand Constituents (Percent) Ilmenite | Garnet | Zircon | Scheelite | | | | Remarks | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 1 |
| | | | | | | | | | | 2 |
| | | | | | | | | | | 3 |
| | | | | | | | | | | 4 |
| | | | | | | | | | | 5 |
| | | | | | | | | | | 6 |

Comments: ______________________________

NOTE: This is an example of the data sheet on which placer lab results are reported. If the sample volume is included on the data sheet sent to the lab, volume and value can be determined by the lab.

# Chapter VI: Reserve Calculation Methods

# Analysis and Evaluation

After accumulating sufficient deposit information, the evaluator must create a combined data set from which the entire deposit can be characterized. Initially the three main pieces of data are the sample interval, sample volume, and amount of gold recovered for each sample. As shown in figure 6.1, each site can have multiple samples, and these are commonly inconsistent with regard to grade. The disparities must be reconciled before a determination is made about the mine feasibility, a mining plan, and the overall economics of the deposit. A major source of confusion in this process is the use of in-place volumes (bcy) vs. the larger volume of material to be processed after excavation (lcy). Unfortunately, reserve calculations usually use both sets of numbers, which may be considerably different due to the swell factor of excavated material. Using the wrong set of data can drastically affect projected reserves and economics; this will be discussed in the following sections.

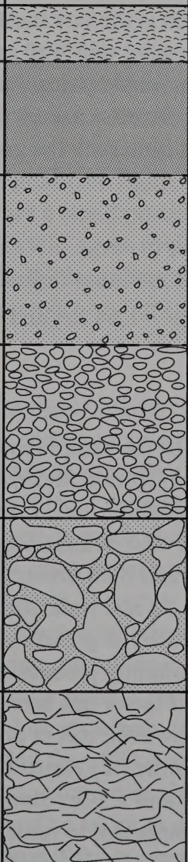
| Sample volume | Sample interval | Stratigraphic column | Material type | Gold recovered |
|---|---|---|---|---|
| 1 bcy | 1 ft |  | topsoil | 0 mg gold |
| 4 bcy | 2 ft | | 100% sand | 10 mg gold |
| 6 bcy | 3 ft | | 10% pebbles; 90% sand | 45 mg gold |
| 5 bcy | 3 ft | | 2-in well-rounded gravel | 122 mg gold |
| 8 bcy | 3 ft | | 70% boulders and cobbles; 30% clay and fine sand | 3246 mg gold |
| 4 bcy | 3 ft | | Thinly layered metamorphic bedrock | 2243 mg gold |

Figure 6.1. Stratigraphic column with raw data.

## Calculation of Sample Grade

The sampling and testing process provides a result in grams or milligrams of gold recovered per sample interval of a given sample volume. Although various units can be used to define the grade of placer deposits, in the United States the convention is grams per cubic yard. Additionally, the end value needs to be reported in both grams and dollars per cubic yard. The first value allows the evaluator to experiment with how sensitive the economics are to commodity prices. The second allows the evaluator to derive a number comparable to the expected cost of operations.

In the calculation of grams per cubic yard, the recovered weight of the gold must be converted to grams. If it is in milligrams, the value must be divided by 1,000. For example, if the sample yields 28.6 mg of gold, it is actually:

$$\frac{1\text{ g}}{1{,}000\text{ mg}} \times 28.6\text{ mg} = 0.0286\text{ g of gold.}$$

According to convention in the United States, the original sample volume is calculated in bcy. The bcy represent the in-place volume of sample material; lcy represent the disturbed volume, which is the bcy multiplied by the swell factor (decimal equivalent). If the volume of material removed can be measured it will be reported as cubic inches, cubic feet, or cubic yards, but the end value must be in cubic yards. If a property was drilled, the hole was cased with a 10-in-diameter casing, and the sample was done on a 3-ft vertical interval, the conversion formula for determining the sample volume would be:

vertical interval x area of drill pipe
3 ft x $\pi r^2$, where $\pi = 3.14$ and $r$ = inner radius of the drill pipe,
3 ft x $\pi$ (5/12 ft)$^2$ = 3 ft x 0.55 ft$^2$ =1.64 ft$^3$, and

$$\frac{1.64\text{ ft}^3}{27\text{ft}^3/\text{yd}^3} = 0.06\text{ bcy.}$$

This represents the bcy volume of the sample intersected by the casing. If the sample volume was measured after collection, the volume would be in lcy. The two numbers must not be used interchangeably.

The swell factor is calculated by first determining the in-place (bcy) sample volume and the recovered (lcy) volume and then dividing the lcy value by the bcy value. The swell factor should normally be >1 and indicates the additional porosity created during sampling. This additional porosity is greatly influenced by the character of the original material, as well as by the sampling process itself, so it will rarely be constant throughout most deposits. If the swell factor has been accurately determined, it can be used to convert lcy to bcy values. However, this is prone to errors, and grade calculations based on recovered sample volume (lcy) must be used with caution. For example, if a bulk sample was taken and a 5-lcy sample that represented a vertical interval of 3 ft was processed, it is important to remember that the result is in lcy and should be converted to bcy. If during testing it was determined that the swell of the gravel was 34 percent, the bcy volume can be calculated as follows:

Sample volume recovered (SVR) x (1 + swell factor) = 5 lcy, so

$$SVR = \frac{5 \text{ lcy}}{1.34} = 3.73 \text{ bcy}.$$

In the example shown in figure 6.2, the amounts of gold recovered in each sample (figure 6.1) have been converted to gold weights per volume of sample and dollar value per volume of sample. For example, the price of gold is assumed to be $300/troy oz, and there are 31.1035 g of gold per troy ounce; at this price, the value of a gram of gold is:

$300/troy oz ÷ 31.1035 g/troy oz = $9.65/g.

To obtain the value of the sample (and subsequently the ground represented by the sample), the value per gram (at the current gold price) is multiplied by the grams recovered per volume of sample:

$9.65/g x 0.029 g/bcy = $0.19/bcy.

## Fineness

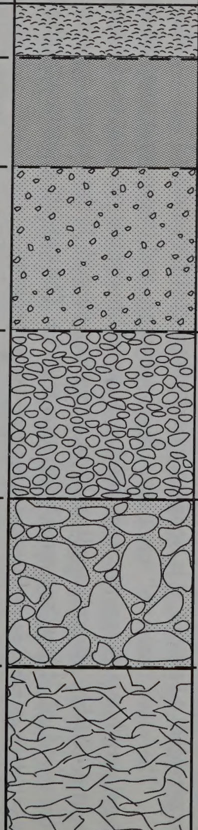
In the above calculations the difficulty arises that this number represents the value of the gold in each bcy as pure gold. Because pure gold does not occur in nature, the sample value must be further reduced by a factor of its fineness. For example, if the fineness is 846, the sample value must be multiplied by 0.846, which yields the diminished, true value of the gold (see figure 6.2, far right column). Although there is some potential to recapture a small portion of the loss in value through the sale of the silver, not all refineries will agree to pay for the silver, and at $4 to $5/troy oz silver, it is usually a small offset. Placer deposits for which the gold is said to be pure should be viewed with suspicion.

## Cut-Off Grades

Sample values (figure 6.2, far right column) have little economic meaning unless they are viewed in relation to the cost of recovering the gold. Consequently, in order to establish a reserve, it is necessary to derive a cost for mining.

The word "reserve" has a strict legal meaning, and improper usage can generate legal problems. A reserve is defined as mineral concentrations that can be mined and sold profitably after all applicable costs are considered. If the deposit does not meet this standard, it is a "resource" but not a reserve. The cut-off grade marks the boundary between what is defined as a reserve vs. a resource.

In 1999, the Society for Mining, Metallurgy, and Exploration (SME) published international guidelines for reporting mineral resources and mineral reserves (SME, 1999). These guidelines are based on standards established by the SME in 1991 (SME,1991). The definitions within the 1991 document have been recognized by most governmental bodies, as demonstrated in United States vs. Vanderbilt, April 19, 1993 (I26IBLA72). Great care must be taken to ensure adherence to the definitions and standards. This is especially true if the mineral property will be offered for sale, if funds are to be raised through a public offering, or if a surface use authorization or other benefit is sought from a governmental agency.



| Sample volume | Sample interval | Stratigraphic column | Material | Raw gold recovered | Raw gold weight (g/bcy) | Raw gold value ($/yd³) $300/troy oz Au | Gold value adjusted for fineness (846) $/bcy pure gold |
|---|---|---|---|---|---|---|---|
| 1 bcy | 1 ft | | topsoil | 0 mg | -0- | -0- | -0- |
| 4 bcy | 2 ft | | 100% sand | 10 mg | $\frac{0.01\text{ g}}{4\text{ bcy}} = \frac{0.03\text{ g}}{\text{bcy}}$ | $\frac{\$0.28}{\text{yd}^3}$ | $\frac{\$0.24}{\text{bcy}}$ |
| 6 bcy | 3 ft | | 10% pebbles; 90% sand | 45 mg | $\frac{0.045\text{ g}}{6\text{ bcy}} = \frac{0.008\text{ g}}{\text{bcy}}$ | $\frac{\$0.08}{\text{yd}^3}$ | $\frac{\$0.06}{\text{bcy}}$ |
| 5 bcy | 3 ft | | 2-in well-rounded gravel | 122 mg | $\frac{0.122\text{ g}}{5\text{ bcy}} = \frac{0.02\text{ g}}{\text{bcy}}$ | $\frac{\$0.19}{\text{yd}^3}$ | $\frac{\$0.16}{\text{bcy}}$ |
| 8 bcy | 3 ft | | 70% boulders and cobbles; 30% clay and fine sand | 3246 mg | $\frac{3.246\text{ g}}{8\text{ bcy}} = \frac{0.405\text{ g}}{\text{bcy}}$ | $\frac{\$3.90}{\text{yd}^3}$ | $\frac{\$3.29}{\text{bcy}}$ |
| 4 bcy | 3 ft | | thinly bedded metamorphic bedrock | 2243 mg | $\frac{2.243\text{ g}}{4\text{ bcy}} = \frac{0.561\text{ g}}{\text{bcy}}$ | $\frac{\$5.40}{\text{yd}^3}$ | $\frac{\$4.57}{\text{bcy}}$ |

Figure 6.2. Stratigraphic column with calculated values of recovered gold.

Within the industry, cut-off grades, or the determination between ore and waste, are divided into two categories: external and internal. The external cut-off is used in the determination of operational feasibility prior to development. It typically includes the costs of exploration, permitting, land purchase, royalties, pre-development, development, capital, operations, sales, and reclamation. Once in operation with the infrastructure constructed, the company may choose to use an internal cut-off grade, which only considers costs such as direct operations, consumable capital, and specific additional infrastructure costs created by increased process volume. An example of additional infrastructure might be an enlargement of the process pond. An example of consumable capital costs would be the total anticipated capital cost of a machine, divided by the projected life of the machine in hours. This provides a rate (dollar per hour) that can be added to operating and labor costs in the determination of the total cost incurred in mining and processing the pay gravels.

The external cut-off grade is derived by dividing the total costs expected to be incurred during the proposed operation by the lcy of resource. Because reserves are calculated in bcy and costs are calculated in lcy, the reserves must be changed to lcy for any of these evaluation calculations. The lcy of the resource is calculated by the following:

$$\text{resource (bcy)} \times \frac{\%\ \text{swell} + 1}{100} = \text{resource (lcy)},$$

or

$$154{,}964\ \text{bcy} \times \frac{(32\%\ \text{swell} + 1)}{100} = 207{,}651\ \text{lcy}.$$

Calculation of the external cut-off grade is an interactive process. The actual cut-off cost on a property can be estimated only after at least two iterations. Initially, an evaluator derives reserve estimates from resources by using an estimate of the expected cut-off grade ($/lcy). This number can be obtained from operating mines that function under similar conditions or can be estimated from similar properties that have been evaluated. Reasonable cut-off estimates, including costs current in 2000, would be $4.00/lcy for gravel deeper than 20 ft and $3.00 for gravel less than 20 ft deep; in other words, pay gravel containing gold in quantities less than these numbers would not be a reserve.

After a preliminary reserve is estimated, then detailed costing should be completed based on the estimated reserves. A mine design and material handling sequence, which will establish the distances and volumes of material to be moved and consequent costs, must then be created. After the costs are estimated, a more accurate cut-off can be developed. This number is then reapplied to the resource data, which may then change the volumes of pay gravel and waste, which in turn will change the costs. These new costs will create a new cut-off that will start the iteration over again. Each iteration will provide a more accurate number than the last, until changes are too small to be of concern.

Costs are heavily influenced by how many times the material must be handled and the distance of transportation. For example, the cost of trucking gravel 2,500 ft (with a 40-ton articulated truck and a 5-$yd^3$ excavator at $0.74/lcy) is nearly twice as high as the cost for trucking it 600 ft ($0.43/lcy). If the gravel can be moved with a large dozer on short downhill pushes or with a dragline or excavator, costs may be as low as $0.10 to $0.20/lcy. By applying costs for various mining and handling pro-

cesses during the iterative process, estimators can establish the optimal cut-off grade to maximize both profitability and recovery of the resource.

## Dilution Factors

If the samples shown in figure 6.2 were judged to have been diluted by waste, the volume of each sample should be discounted by the percentage of the dilution. Consequently, if a 4-bcy sample experienced 20 percent dilution, the actual volume would be as follows:

(4 bcy) - (4 bcy x 0.20) = 3.2 bcy.

This would effectively increase the calculated sample grade. The correction would most commonly be applied during bulk sampling. Since this is an estimate as opposed to a measurement, it is advisable to maintain two separate reserve estimates: one should be calculated with the dilution factors and one without. At the end of the evaluation process, it is better to compare the values and judge the sensitivity of the results. If the property is economic without the dilution factors, it will certainly be economic with them.

The dilution may resemble actual mining conditions, and if the property is economic only after applying the adjusting dilution factors, then unless the sampling conditions were terrible the deposit may be marginal and quite sensitive to any mistakes made during production. The judgment call between these two reserve numbers will be dependent on the experience of the evaluator.

## Pay Zone Determination

If a cut-off value of \$3/lcy is used during the first cycle on figure 6.2, then only the bottom 6 ft are classed as pay gravel reserves; all of the rest of the material is waste or overburden. Therefore, in figure 6.2, 9 ft of waste covers 6 ft of pay gravel.

To calculate the average value of the combined sample pay zones, a weighted average method is used wherein the thickness of the zone is multiplied by the value or grade as shown below:

$$\begin{array}{lcccc} \underline{\text{interval}} & & \underline{\text{grade}} & & \underline{\text{interval x grade}} \\ 3\text{ ft} & \text{x} & \$3.29/\text{lcy} & = & \$9.87\text{ ft/lcy} \end{array}$$

$$+\frac{3\text{ ft}}{6\text{ ft}} \text{ x } \$4.57\text{ lcy} = \frac{\$13.71\text{ ft/lcy}}{\$23.58\text{ ft/lcy}} \text{ (sum of the two intervals)}$$

$$\text{and } \frac{\$23.58\text{ ft/lcy}}{6\text{ ft}} = \$3.93/\text{lcy (weighted average).}$$

If the intervals are the same, or if the value or grade is the same between both samples, an arithmetic average of the combined intervals will give the same answer. Consistent use of weighted averages helps avoid mistakes. Each sample site must be consolidated into pay and waste thicknesses as previously shown.

When the testing program is complete, the next critical production task is the definition of the economic (horizontal or areal) boundaries of the deposit. A common method of estimation for the reserve calculation employs the projection of boundaries halfway between the last pay hole (above cut-off grade) and the first waste hole. The

exact boundary of the deposit can be determined by trenching between these two holes. If the holes are 50 ft apart, it may not be as critical as if the holes are 100 ft apart. The decision for further trenching depends on whether the economics of the deposit can afford to leave 20 to 50 ft of pay gravel unmined, or whether the operation can afford to wash the same amount of barren gravel. The detailed testing to resolve these questions is usually conducted during production or in the pre-production phase.

## Interpreting Erratic Sample Results

When the values of each test pit are nearly the same and the pay zone is at approximately the same elevation in all holes, reserve analysis is simple. This situation may be common in large transport-type deposits; however, lag deposits will typically have less predictable results. Figure 6.3 shows a map of a deposit that exhibits erratic values. If only the test data are used, the results are confusing. One side of the valley is shallow; one side is deep. Rich values occur directly downstream from samples with no gold. Samples at the lower end of the deposit show only medium values, while those in the center are exceedingly rich.

The information the evaluator gathered on the deposit now becomes critical. Figure 6.4 exhibits additional data from which interpretations can be drawn. Line 1 is bisected diagonally by a gold-bearing quartz vein. The fact that a stamp mill was on the property almost certainly confirms the presence of lode gold. The placer gold found on Line 1 should contain large amounts of quartz inclusions and quartz crystals if it was derived from the vein. If the load source had been a skarn, then garnets, magnetite, and possibly diopside would have been the accessory minerals. If the lode source were a sulfide body, sulfide minerals would be abundant in the concentrates. In any case, the size distribution of the gold should be similar to that in the lode deposit. Typically, colluvial deposits will be more erratic with more angular rock present than in the gulch placer. Values may be locally high, low volume, and shallow.

Line 2 intersects a resistant dike that trapped coarse gold on the upstream side, as reflected in the rich values at the east end of the line. The cumulative weight distribution of these samples may show the gold sorted heavily to the larger pieces. Immediately downstream of the dike, a barren zone may exist where the small gold particles escaped the upstream trap and were carried farther downstream in suspension.

A cumulative weight distribution of the gold particles from samples along Line 3 may show that the distribution of sizes is concentrated in the smaller ranges. The values may disappear quickly below Line 3 if the bedrock gradient flattens. Commonly, the smallest gold particles will be transported great distances, especially on a smooth-lying bedrock such as argillite.

The steeply dipping quartzite between Lines 1 and 2 shown in figure 6.4 provided a ragged bedrock channel bottom in which to capture the moving gold. The pay zone, as indicated by the deeper holes and higher values, likely indicates the location of a paleochannel during gold deposition.

## Reserve Calculations for Lag Deposits

The preliminary step in resource/reserve calculations should be to determine a method for establishing a reasonable area of influence for each sample site. Geostatistics are ineffective in the calculation of most placer reserves because of the large variability in values and the limited number of samples. The isoline system outlined

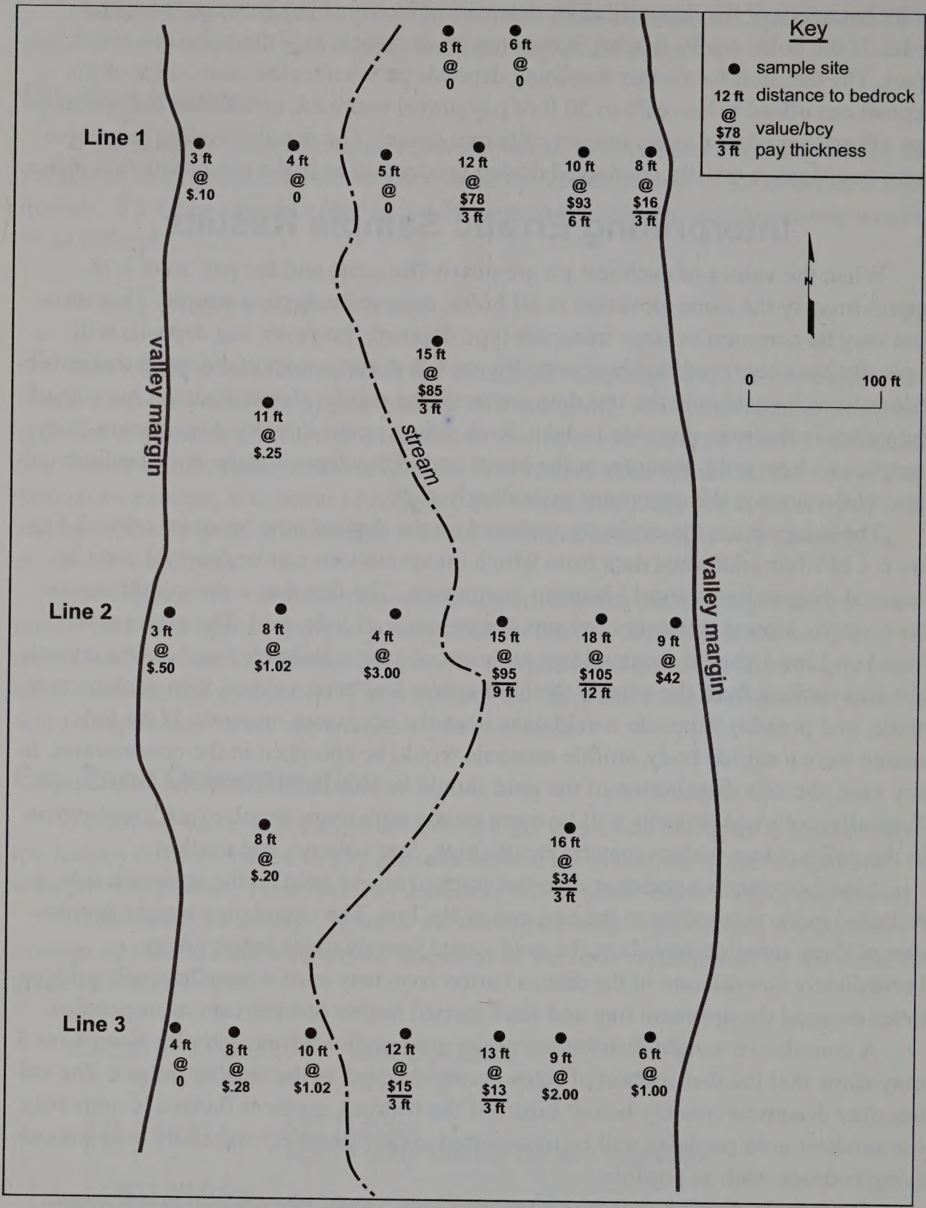



Figure 6.3. Surface map showing erratic values.

by Popoff (1966) lacks sample detail, and most deposits are too narrow to allow the detail necessary for effective use of this tool. The triangle system does not work well in sampling systems that have large length to width ratios in the area of influence between holes or in situations with discrete geologic unit boundaries, and it tends to bias the results unless the sample sites happen to correspond well with the unit boundaries. For lag deposits, the three most viable methods available for estimating areas of influence are the polygons, block model, and cross section, as outlined in U.S. Bureau of Mines Information Circular 8283 (Popoff, 1966).

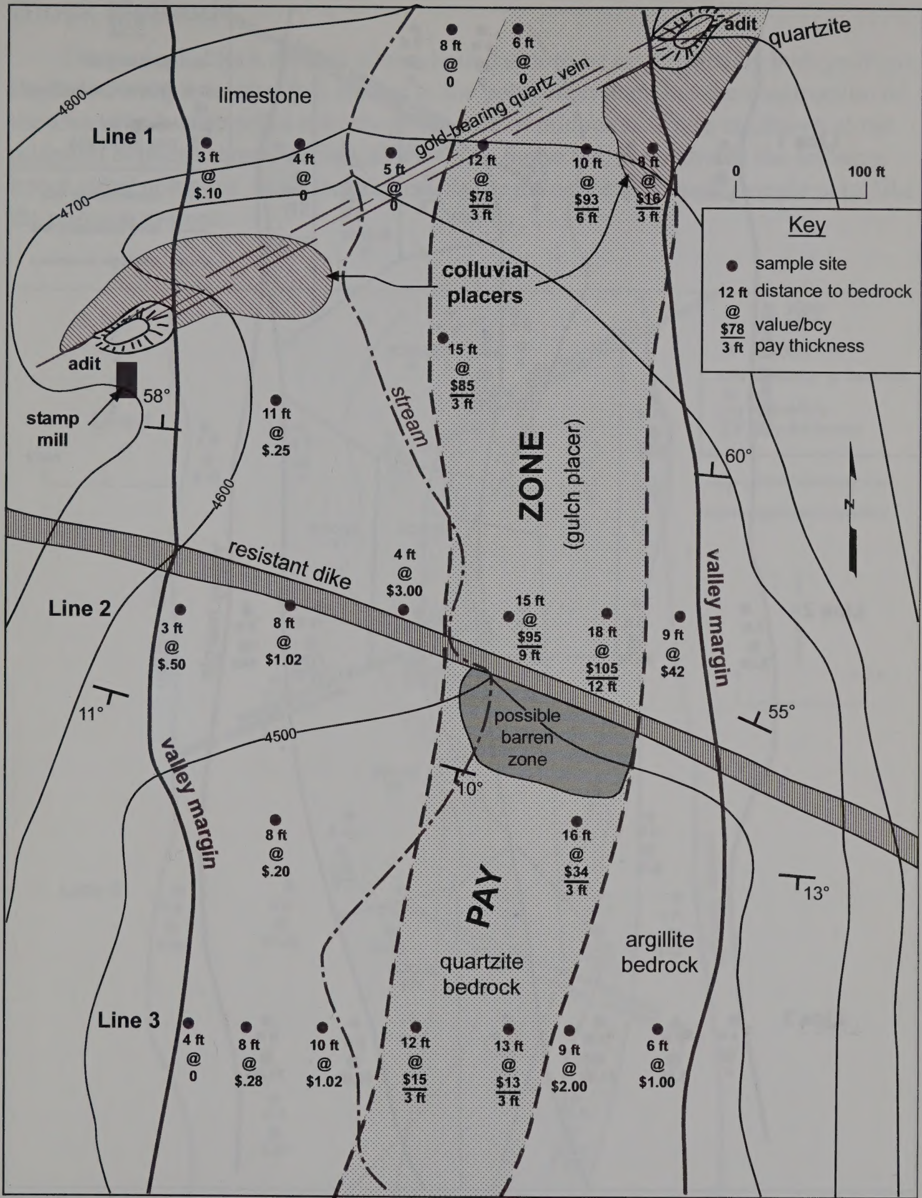


Figure 6.4. Surface map of deposit showing geologic influences.

## Polygon Method

As the name implies, the polygon method allows estimators to calculate reserves by systematically dividing the deposit into a series of polygons that are based on sample site locations and deposit boundaries.

As described by Popoff (1966), the property and test sites must be surveyed and represented on a map at a "reasonable" scale. The geologic boundaries should be depicted on the map, along with the deposit boundaries. Connecting lines between sample sites should be established under the rule that no lines cross each other (figure 6.5, note dashed

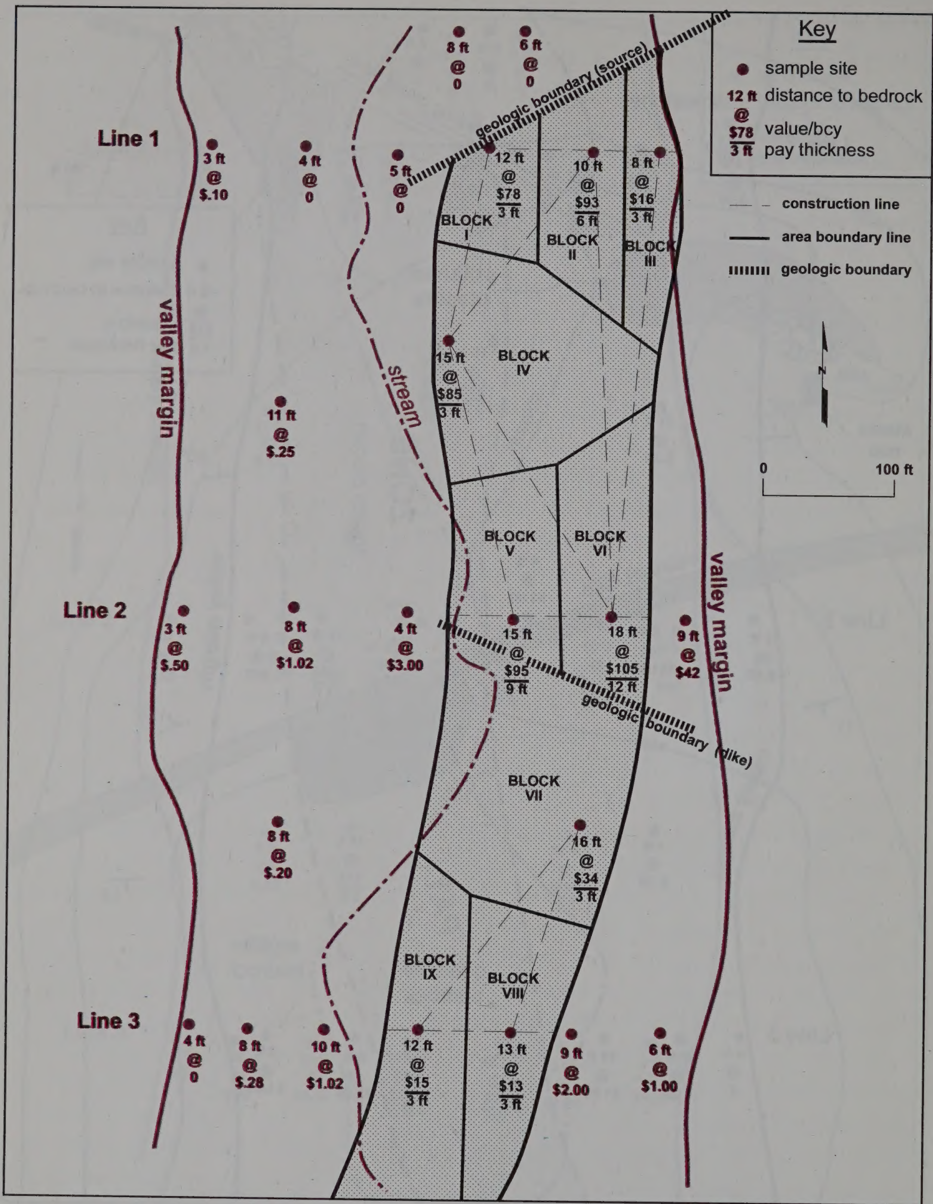



Figure 6.5. Reserve calculation using the polygon method (based on the hypothetical deposit shown in figures 6.3 and 6.4).

lines). When this is completed, perpendicular bisectors are added. Each should be projected until it intercepts a geologic boundary or another construction line. The area that surrounds a single sample site and is bounded by linking perpendicular bisectors is the area of influence of that site. Estimators can derive the area of each polygon with a planimeter or by digitizing the boundaries and using a computer program to determine the area. Finally, estimators can use a third method of overlaying a grid and counting the squares or dots of the known area within each polygon, which provides simple and fast results; however, though convenient, this is not as accurate as other methods.

## Block Method

The geologic block method allows boundaries to be established by both geologic limits and sample results. It is similar to the polygon system, but the construction of the area of influence relies entirely on the rule of midpoints. Lines are drawn at the midpoint between sample points, as shown in figure 6.6, to subdivide the resource into 4-sided polygons. Each area represents the influence of a single sample point like the polygon system.

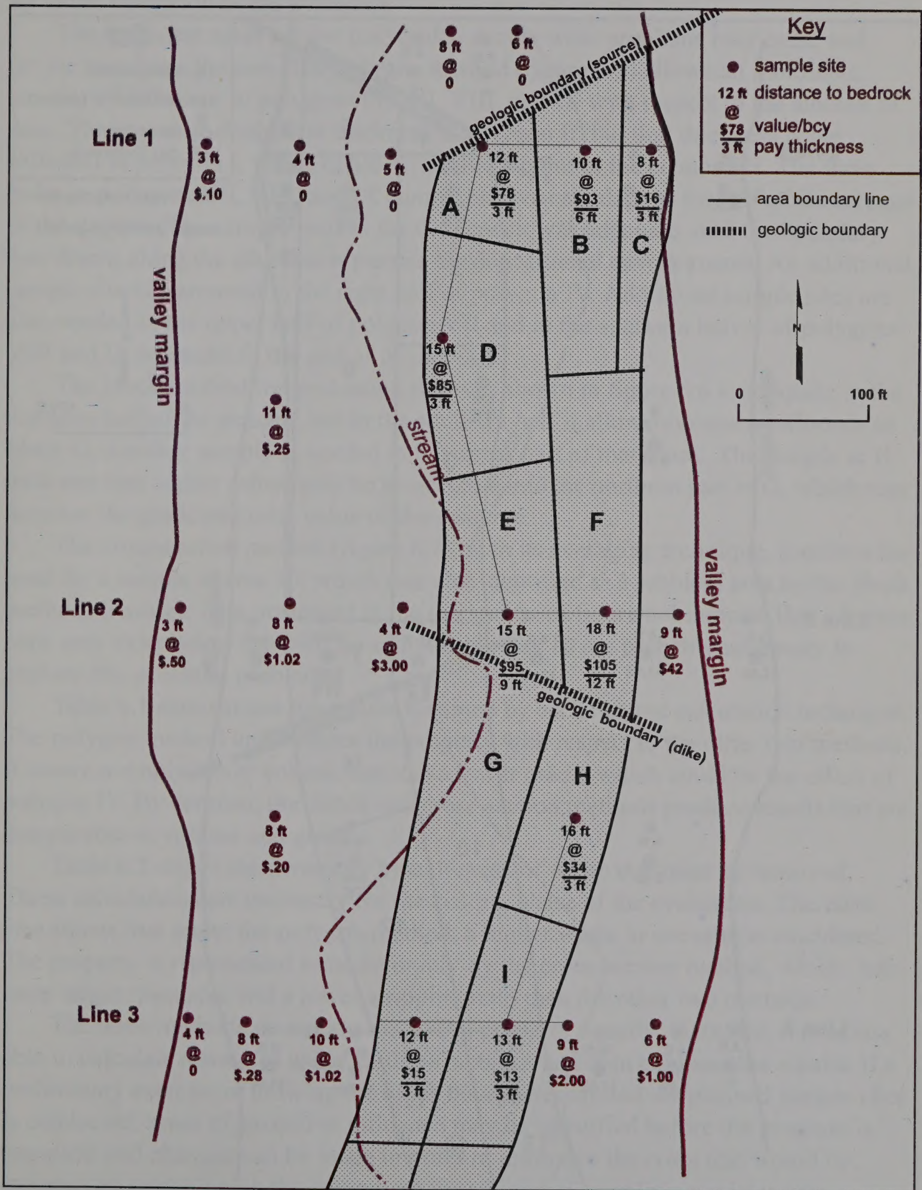



Figure 6.6. Geologic block method.

## Cross-Section System

The cross-section system is similar to the geologic block method except that each area of influence is controlled by the average of the end points of the block instead of a single point (figure 6.7). This system averages depths of pay zones and grade earlier than the other systems.

Blocks not having two points project the influence of a single point to the geologic or economic boundary in the same way as the other methods. End blocks should not be projected more than half the distance to the closest consecutive sample in the last block.

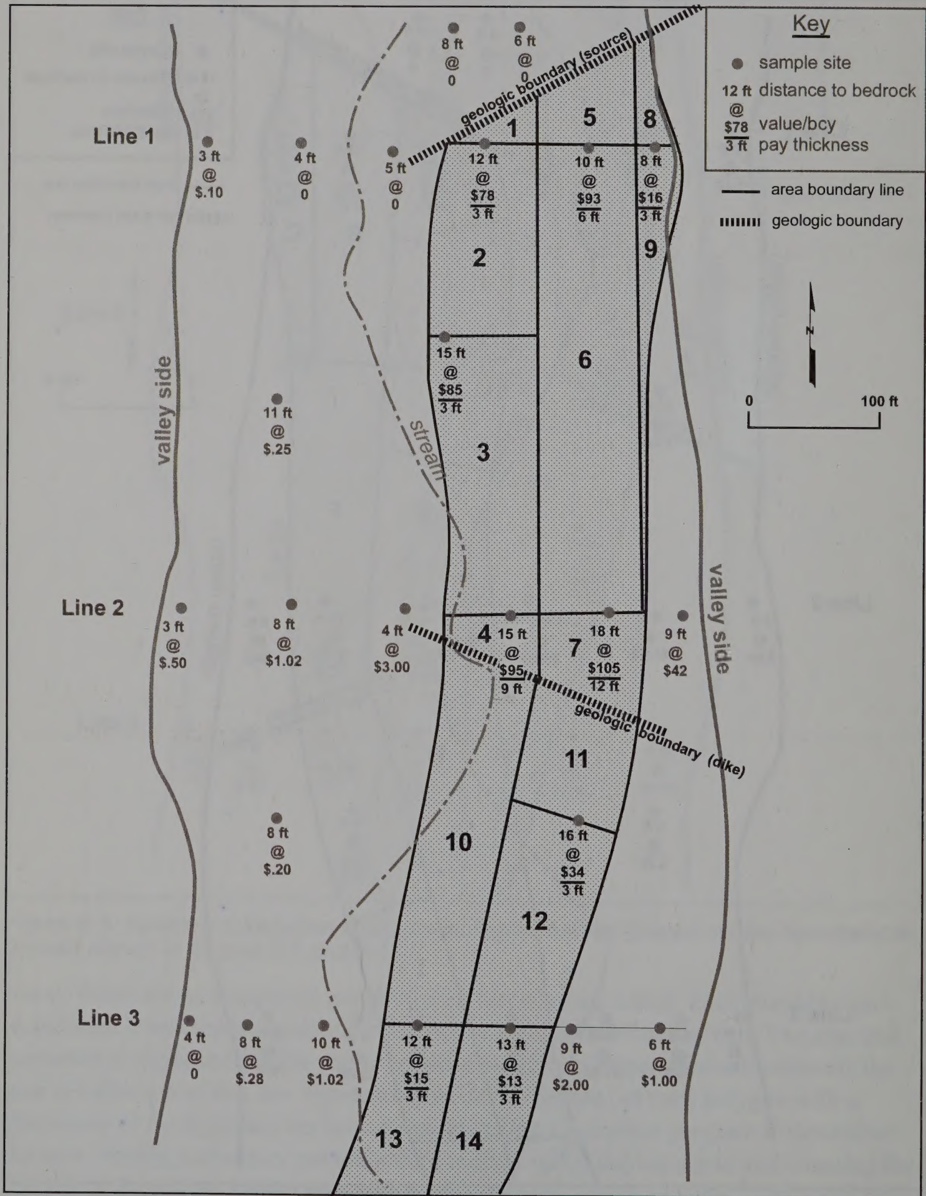



Figure 6.7. Cross-section method.

## Comparative Analysis

Looking at the illustrations of the three reserve estimation methods shown in figures 6.5–6.7, the evaluator should note that the deposit is open on the southern end (bottom of each figure), because sampling did not extend downstream far enough to define the southern limits of the deposit. With this end open, each evaluation method creates a different boundary. The block model utilizes the law of approximate distances, in that half the distance to a known point is equal to an accepted distance to an unknown point, while the polygon and cross-section methods leave the issue totally up to the discretion of the evaluator.

The evaluator must review the results, decide what problems may exist, and devise possible solutions. The polygon method (figure 6.5) allows an inordinate amount of influence to polygons IV, VII, VIII, and IX with respect to the amount of data. The pay zone doubles in thickness in polygon II, but that thickness is not reflected in polygon I, which could be a critical point in the economics. The three holes in polygons VII, VIII, and IX control reserve calculations for half of the acreage of the deposit. The sample pattern for the deposit was adequate until the boundary was drawn along the dike that separates the depositional environments. An additional sample site is warranted in the right half of polygon IV. Additional sample sites are also needed in the upper half of polygon VII and in the southern halves of polygons VIII and IX to establish the end of the deposit.

The block method for evaluating reserves shown in figure 6.6 is adequate in the northern half of the deposit, but in the southern half it allows too much influence to block G. Another sample is needed in the upper half of that block. The sample in H indicates that higher values may be projectable into the northern part of G, which may increase the grade and total value of the resource.

The cross-section method (figure 6.7), with its averaging technique, confirms the need for a sample in area 10, which was also identified as a problem area by the block method. Geologic data presented in the discussion of figure 6.4 indicate that a barren zone may exist below the dike, so samples in Area 10 are probably necessary to explore this potential problem.

Table 6.1 summarizes the results obtained by each reserve calculation technique. The polygon method undervalues the property with respect to the other two methods. It shows not only lower volume but also a lower grade, which could be the effect of polygon IV. By contrast, the block and cross-section methods produce results that are comparable in volume and grade.

Table 6.2 shows the inventory by unit areas of waste that must be removed. These calculations are necessary for the costing phase of the evaluation. The table also shows that under the polygon method, a higher waste to ore ratio is calculated. The property is represented most favorably by the cross-section method, which indicates larger resources and a lower stripping ratio than the other two methods.

The three methods do not always treat a property equally; therefore, it is advisable to calculate resources using all three methods and then compare the results. If a preliminary exercise of drawing the block boundaries around the planned sample sites is conducted, areas of excessive influence may be identified before the program is complete and changes can be made in order to minimize the costs that would be incurred by remobilizing the equipment for additional sampling at a later time.

Table 6.1 Volume and grade calculations for pay gravel

| Method | Pay gravel reserves block | Area A (ft$^2$) | Pay zone thickness T (ft) | Grade G ($/yd$^3$) | Volume (A x T (yd$^3$)) 27 | (V x G=bcy) | Average grade (bcy) | Stripping ratio |
|---|---|---|---|---|---|---|---|---|
| Polygon | I | 2,175 | 3 | 78 | 242 | 18,876 | | |
| | II | 2,825 | 6 | 93 | 628 | 58,404 | | |
| | III | 1,850 | 3 | 16 | 206 | 3,296 | | |
| | IV | 6,650 | 3 | 86 | 739 | 62,815 | | |
| | V | 2,875 | 0 | 95 | 958 | 91,010 | | |
| | VI | 3,850 | 12 | 105 | 1,711 | 179,655 | | |
| | VII | 7,650 | 3 | 34 | 850 | 28,900 | | |
| | VIII | 3,775 | 3 | 13 | 419 | 5,447 | | |
| | IX | 6,475 | 3 | 15 | 719 | 10,785 | | |
| | | | | | 6,472 | 459,188 | $\frac{459{,}188}{6{,}472}$ = $70.95/bcy | 1.99 : 1 |
| Geologic block | A | 2,100 | 3 | 78 | 233 | 18,174 | | |
| | B | 4,400 | 6 | 93 | 978 | 90,954 | | |
| | C | 2,650 | 3 | 16 | 294 | 4,704 | | |
| | D | 4,725 | 3 | 85 | 525 | 44,625 | | |
| | E | 3,000 | 9 | 95 | 1,000 | 95,000 | | |
| | F | 5,000 | 12 | 105 | 2,222 | 233,310 | | |
| | G | 7,925 | 3 | 15 | 880 | 13,200 | | |
| | H | 3,975 | 3 | 34 | 442 | 15,028 | | |
| | I | 3,625 | 3 | 13 | 403 | 5,239 | | |
| | | | | | 6,977 | 520,234 | $\frac{520{,}234}{6{,}977}$ = $74.56/bcy | 1.6 : 1 |
| Cross section | 1 | 350 | 3 | 78 | 39 | 3,042 | | |
| | 2 | 3,600 | 3 | $\frac{78 + 85}{2} = 81.5$ | 400 | 32,600 | | |
| | 3 | 5,000 | $\frac{3+9}{2} = 6$ | $\frac{((85\times3)+(95\times9))}{9+3} = 92$ | 1,111 | 102,767 | | |
| | 4 | 575 | 9 | 95 | 192 | 18,240 | | |
| | 5 | 1,400 | 6 | 93 | 311 | 28,923 | | |
| | 6 | 7,350 | $\frac{6+12}{2} = 9$ | $\frac{((93\times6)+(105\times12))}{12+6} = 101$ | 2,450 | 247,450 | | |
| | 7 | 1,200 | 12 | 105 | 533 | 55,965 | | |
| | 8 | 950 | 3 | 16 | 106 | 1,696 | | |
| | 9 | 1,525 | 3 | 16 | 169 | 2,704 | | |
| | 10 | 5,950 | 3 | 15 | 661 | 9,915 | | |
| | 11 | 2,025 | 3 | 39 | 225 | 8,775 | | |
| | 12 | 3,000 | 3 | $\frac{39 + 13}{2} = 26$ | 333 | 8,658 | | |
| | 13 | 2,675 | 3 | 15 | 297 | 4,455 | | |
| | 14 | 1,975 | 3 | 13 | 219 | 2,847 | $\frac{528{,}037}{7{,}046}$ = $74.94/bcy | 1.37 : 1 |
| | | | | | 7,046 | 528,037 | | |

## Reserve Calculations for Transport Deposits

Transport deposits are usually a lower grade, contain smaller gold particles, and are represented by somewhat more uniform sample values than other types of deposits. Most transport deposits involve large volumes of resources and are amenable to bulk-mining techniques that include bucket-line dredges and large-scale truck-loader excavation. These deposits are much more extensive than lag deposits and are sampled with the use of equidimensional grid systems. Because of these parameters, resource calculation techniques such as triangle and isoline methods may be used in addition to those previously discussed.

Table 6.2 Volume calculations for strip material

| Method | Waste totals block | Area A (ft$^2$) | Waste thickness T (ft) | Volume $\frac{(A \times T\ (yd^3))}{27}$ |
|---|---|---|---|---|
| Polygon | I | 2,175 | 12 - 3 = 9 | 725 |
| | II | 2,825 | 10 - 6 = 4 | 418 |
| | III | 1,850 | 8 - 3 = 5 | 343 |
| | IV | 6,650 | 15 - 3 = 12 | 2,955 |
| | V | 2,875 | 15 - 9 = 6 | 639 |
| | VI | 3,850 | 18 - 12 = 4 | 570 |
| | VII | 7,650 | 16 - 3 = 13 | 3,683 |
| | VIII | 3,775 | 13 - 3 = 10 | 1,398 |
| | IX | 6,475 | 12 - 3 = 9 | 2,158 |
| | | | | 12,889 bcy |
| Geologic block | A | 2,100 | 12 - 3 = 9 | 700 |
| | B | 4,400 | 10 - 6 = 4 | 652 |
| | C | 2,650 | 8 - 3 = 5 | 491 |
| | D | 4,725 | 15 - 3 = 12 | 2,100 |
| | E | 3,000 | 15 - 9 = 6 | 667 |
| | F | 5,000 | 18 - 12 = 4 | 741 |
| | G | 7,925 | 12 - 3 = 9 | 2,642 |
| | H | 3,975 | 16 - 3 = 13 | 1,914 |
| | I | 3,625 | 13 - 3 = 10 | 1,343 |
| | | | | 11,250 bcy |
| Cross section | 1 | 350 | 12 - 3 = 9 | 117 |
| | 2 | 3,600 | $\frac{((12-3)+(15-3))}{2} = 10.5$ | 1,400 |
| | 3 | 5,000 | $\frac{((15-3)+(15-9))}{2} = 7.5$ | 1,111 |
| | 4 | 575 | 15 - 9 = 6 | 127 |
| | 5 | 1,400 | 10 - 6 = 4 | 207 |
| | 6 | 7,350 | $\frac{((10-6)+(18-12))}{2} = 4$ | 1,089 |
| | 7 | 1,200 | 18 - 12 = 4 | 178 |
| | 8 | 950 | 8 - 3 = 5 | 176 |
| | 9 | 1,525 | 8 - 3 = 5 | 282 |
| | 10 | 5,950 | 12 - 3 = 9 | 1,983 |
| | 11 | 2,025 | 16 - 3 = 13 | 975 |
| | 12 | 3,000 | $\frac{((16-3)+(13-3))}{2} = 11.5$ | 128 |
| | 13 | 2,675 | 12 - 3 = 9 | 892 |
| | 14 | 1,975 | 13 - 3 = 10 | 731 |
| | | | | 9,674 bcy |

## Isolines

This system joins all points of equal unit value like a topographic map and is best used where large numbers of data points are available. Numerous computer software packages are available that can rapidly contour multiple types of numerical data such as grade and thickness, in addition to producing derivative information such as reserve tonnage, stripping ratios, and waste volumes. The resulting maps tend to be visually intuitive, but the evaluator must remember that the computer is only processing numbers. Interpretation of the results based on field observations is still necessary.

## Triangles

The triangle system is constructed on a plan-view map of a deposit. A line is drawn between each sample site without crossing another line, so that a series of triangles with a sample site at each apex is generated. The three data points are used to determine the value assigned to each triangle according to the "law of gradual changes" (Popoff, 1966). The formula for computing the volume of a solid triangular prism is:

$$\text{volume} = \frac{(t_1 + t_2 + t_3)}{3} \text{ x area,}$$

where $t_1$, $t_2$, and $t_3$ are thicknesses at the corners of the triangular area. The average grade of each prism may be determined as a grade-thickness weighted average under the formula:

$$\frac{(g_1 \text{ x } t_1) + (g_2 \text{ x } t_2) + (g_3 \text{ x } t_3)}{(t_1 + t_2 + t_3)},$$

where $g$ is grade and $t$ is thickness. The average grade of the deposit is the volume-grade weighted average of the sum of the triangles as previously shown. This method should be used in conjunction with the other methods, and the most representative should be chosen. Of the two methods, isolines is probably used more often. AutoCad® drafting packages utilize the method of isolines.

# Reserve Encumbrances

## Overburden

Properties with excessive overburden may be constrained by an additional limitation. Pit-wall stability and associated safety concerns may limit how much of a pay zone can be mined. Whereas 20 ft of dry, consolidated gravel may stand in a near-vertical face, it is unlikely that 10 ft of wet gravel or 40 ft of dry gravel will. Again the evaluator must determine the field conditions and establish limits for the recoverable reserves by determining the minable pit boundaries of the resource.

## Multiple Pay Zones

Multiple pay zone evaluations (figure 6.8) utilize the same criteria as single pay zones. Mining of the uppermost pay zone exposes the top of the next mining unit. That unit now has a lower strip ratio and may become economic under the new conditions. When it is mined, the next underlying zone may become economic. Each zone above a pay zone may in turn pay for stripping the one below.

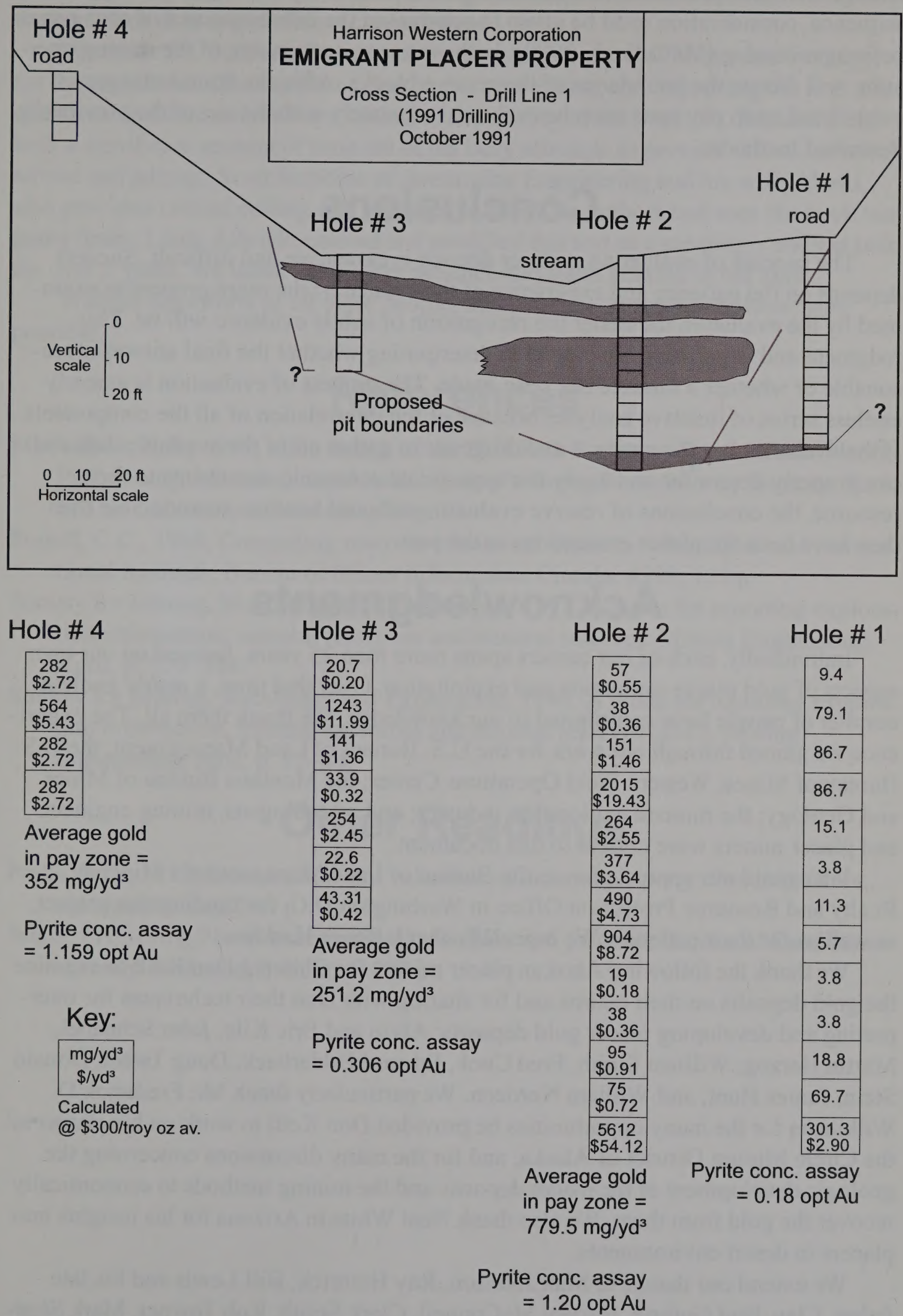



Figure 6.8. A cross section of the Emigrant placer property, Emigrant, Montana, showing multiple pay zones (McCulloch, 1999).

Additional problems occur in multiple pay zones when the overburden volumes exceed storage capacities within the mine panel. Often, in planning the mining sequence, consideration must be given to removal of the entire resource of each panel before processing (McCulloch, 1999). In those cases, sequencing of the mining operation will dictate the boundaries of the reserve blocks. After the boundaries are established, each pay zone must be evaluated separately with the use of the previously described methods.

# Conclusions

The process of evaluating a placer deposit is expensive and difficult. Success depends on the patience and experience of the evaluator: the more properties examined by the evaluator, the easier the recognition of subtle evidence will be. This judgment and experience are crucial in determining whether the final answer is reasonable or whether a mistake has been made. The process of evaluation is a nearly endless series of iterative analyses because of the interrelation of all the components. If the evaluator has the patience and diligence to gather all of the available data and can properly determine and apply the appropriate economic constraints to the resource, the conclusions of reserve evaluations should be more reproducible than they have been for placer evaluations in the past.

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# Appendices

# Appendix A
# Glossary of Mining Terms

Many of the following terms have universal definitions; that is, they have definitions common to all branches of the mineral industry. On the other hand, some are unique to the placer industry, or at least they have placer-related meanings that are different from those in general use. For example, the term FLOTATION, as it is generally used in the mining industry, relates to a mineral separation process. However, in placer mining, the term FLOTATION is applied to the minimum water depth needed to move an operating dredge.

The definitions of the following terms are intended to be descriptive rather than legal, and they should be used accordingly. All terms not sourced are from the authors or from Wells (1969) and are related to their use in placer mining.

Names in parentheses refer to sources as follows:

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**ACCRETION BAR** A deposit of sand and gravel formed in a stream by gradual addition of new material. Accretion bars are typically formed along the short, or inside, radius of curves. *See* SKIM BAR.

**ADJUSTED VALUE** A sample value that has been increased or decreased by an amount deemed necessary to offset known variables or other factors that may cause discrepancies in the initially indicated value. In placer drilling, the adjusted value is also known as a CORRECTED VALUE. To be valid, such adjustments must be based on careful diagnoses of sampling problems and must reflect sound judgment. *See* INDICATED VALUE.

**AINLAY BOWL** A wet gravity concentrator used for the recovery of gold and other heavy minerals from alluvial materials. It consists essentially of a bowl-shaped vessel, rotated about its vertical axis and set with circular riffles. Feed entering at the center is carried upward and outward by the flow of water and centrifugal force. Tailings overflow the rim while gold and other heavy minerals are retained by the riffles. A somewhat similar bowl-shaped concentrator is known as the KNUDSEN BOWL.

**AIRPLANE DRILL** A compact, engine-powered placer drill designed for use in areas with difficult access. The term AIRPLANE DRILL is actually a trade name, which has become part of placer mining vernacular through common use.

**ALLUVIAL** 1. Deposited by a stream. 2. Relating to deposits made by flowing water (Fay, 1920).

**ALLUVIAL FAN** A cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream. The fans generally form where streams issue from mountains onto lowland (AGI, 1962).

**ALLUVIAL GOLD** Gold found in association with water-worn material (Fay, 1920).

**ALLUVIAL PLAIN** 1. Flood plains produced by the filling of a valley bottom are alluvial plains and consist of fine mud, sand, or gravel. 2. A plain resulting from the deposition of alluvium by water (AGI, 1962).

**ALLUVIUM** A general term for all detrital deposits that result from the operations of modern rivers, including the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries (AGI, 1962).

**AMALGAM** An alloy of mercury with gold or another metal. In the case of placer gold, a "dry" amalgam, that is, one from which all excess mercury has been removed by squeezing through chamois leather; will contain nearly equal proportions of gold and mercury.

**AMALGAMATION** The extraction of precious metals from their ores by treatment with mercury.

**ANCIENT BEACH PLACER** Deposits found on the coastal plain along a line of elevated beaches (Brooks, 1908).

**ANCIENT CHANNEL** *See* TERTIARY CHANNEL.

**ANNUAL LABOR** *See* ASSESSMENT WORK.

**ARMORED** Protected from erosion. When the creek bed is covered with rocks too large to move by precipitation or snowmelt events, it is said to be armored.

**ASSAY** 1. (verb) To determine the amount of metal contained in an ore (McKinstry, 1908). 2. (noun) The act of making such a determination. 3. (noun) The result of such a determination. *See* FIRE ASSAY.

**ASSAY VALUE** The amount of gold, silver, or other valuable material contained in a sample as shown by assay of that sample.

**ASSESSMENT WORK** The annual work upon an unpatented mining claim on the public domain necessary under the United States law for the maintenance of the possessory title thereto. Same as ANNUAL LABOR (Fay, 1920).

**AURIFEROUS** Containing gold.

**BAJADA PLACER** Placers found in confluent alluvial fans along the base of a mountain range or in a mantle of rock debris along the lower slope of a mountain range in arid regions. The deposits are mainly residual detritus and poorly sorted alluvium found in gulches and on slopes that are subject to occasional torrential rain wash. Bajada is the Spanish term for slope. This term has not found general use in placer mining, as most Bajada placers are referred to collectively as PULSE placers.

**BANK MEASURE (Bank Cubic Yard)** The measurement of material in place, such as gravel in a deposit before excavation. In placer work, values are normally reported as cents per cubic yard, and unless specified otherwise, this means a cubic yard in place, or bank measure. This is usually reported by the notation of *bcy.*

**BANK WATER** *See* BY-WASH.

**BANKA DRILL** A placer drill consisting essentially of a flush-jointed pipe casing equipped with a serrated cutting shoe. The casing is rotated by means of a man- or animal-powered sweep attached to the upper section. Men standing on an

attached platform chop up the drill core and remove it from the casing by means of hand-powered tools. Also known as an EMPIRE DRILL.

**BAR** A deposit of alluvial material above or below the water line of a present stream. Bars may form where the current slackens or changes direction. *See* ACCRETION BAR.

**BATEA** A wide and shallow cone-shaped vessel, usually of wood, used for panning gold. The batea is commonly used in Mexico, Central and South America, and Asia.

**BEACH PLACER** Placers reconcentrated from the coastal-plain gravels by the waves along the seashore (Brooks, 1908).

**BED LOAD** Soil, rock particles, or other debris rolled along the bottom of a stream by the moving water, as contrasted with the "silt load" or "suspended load" carried in suspension (AGI, 1962).

**BEDROCK** The solid rock underlying auriferous gravel, sand, silt or clay, and upon which the alluvial gold rests (Fay, 1920). In placer use, the term bedrock may be generally applied to any consolidated formation underlying the gold-bearing gravel. Bedrock may be composed of igneous, metamorphic, or sedimentary rock. *See* FALSE BEDROCK.

**BENCH PLACER** Gravel deposits in ancient stream channels and flood plains that stand from 50 to several hundred feet above the present streams (Brooks, 1908). These deposits are remnants of other types of placer deposits.

**BLACK GOLD** Alluvial gold coated by black oxide of manganese (Dunn, 1929).

**BLACK SAND** Heavy grains of various minerals which have a dark color and are usually found accompanying gold in alluvial deposits (Fay, 1920). The heavy minerals may consist largely of magnetite, ilmenite, and hematite associated with other minerals such as garnet, rutile, zircon, chromite, amphiboles, and pyroxenes. In Western gold placers, the black sand content is commonly between 5 and 20 lbs per cubic yard of bank-run gravel.

**BLUE GRAVEL** Some of the deeper, water-saturated gravels found in California's Tertiary channels are a distinctive bluish gray, and for this reason early miners referred to them as "blue gravel" or more commonly as"blue lead." At one time they were believed to represent a separate gravel flow, distinct from the overlying red gravels. Actually, these blue gravels represent unoxidized portions of the gravel channels, whereas the red gravels represent the oxidized portions of the same material.

**BLUE LEAD** (pronounced leed) *See* BLUE GRAVEL.

**BOOMING** A variation of ground sluicing in which water is stored in a reservoir and suddenly released to provide a rush of water, in a large volume, which erodes and transports the gravel. Booming is generally employed where water is scarce. In California the contrivances for collecting and discharging water are termed SELF-SHOOTERS. *See* GROUND SLUICING.

**BOULDER FACTOR** An estimate of the percentage of placer sample that is composed of boulders.

**BRAIDED STREAMS** 1. A braided stream is one flowing in several divided and reuniting channels resembling the strands of a braid, with the cause of division being obstruction by sediment deposited by the stream. 2. Where more sediment is being brought into any part of a stream than it can remove, the building of bars becomes excessive, and the stream develops an intricate network of interlacing

channels and is said to be braided (AGI, 1962). 3. Conditions which cause braiding are common in glacial areas where much sediment is added by the melting ice and in semi-arid regions where the transporting power of streams is reduced by seepage and evaporation. In general, such conditions are not conducive to the formation of placers.

**BREAKOUT** A point where a ravine or canyon cuts into, but not through, a channel (Dunn, 1888). Usually applied to buried Tertiary channels. Compare with OUTLET and INLET.

**BREAST** The working face of a prospect drift on the pay lead; the face of a gangway being mined (Dunn, 1888).

**BUCKET-ELEVATOR DREDGE** *See* BUCKET-LINE DREDGE.

**BUCKET-LINE DREDGE** A dredge that excavates materials with a chain of buckets (Fay, 1920). Also known as a connected-bucket dredge. The type of bucket-line dredge generally employed in placer mining is a self-contained digging, washing, and disposal unit, operating in a pond and capable of digging, in some cases, more than 100 ft below water. Its machinery is mounted on a shallow-draft hull, and the dredge backfills its working pit (pond) as it advances. The capacity of individual buckets is used as a measure of dredge size. For example, an 18-ft dredge is equipped with buckets having a struck capacity of 18 $ft^3$ each. *See* DRAGLINE DREDGE and SUCTION DREDGE.

**BULLION** Unrefined gold that has been melted and cast into a bar. In placer mining, the gold sponge obtained by retorting amalgam is commonly melted with borax or other fluxes, then poured into a bullion bar. *See* SPONGE.

**BURIED PLACER** Old placer deposits that have become buried beneath lava flows or other strata (Fay, 1920). *See* TERTIARY CHANNEL.

**BY-WASH** In many cases, hydraulic giants are capable of cutting more material from the bank than can be swept into the sluices by means of the giants alone. In such cases, supplemental water may be brought into the pit by means of a ditch to assist in carrying the material to the sluices. This is locally called BY-WASH, BY-WATER, or BANK WATER. *See* HYDRAULIC GIANT.

**BY-WATER** *See* BY-WASH.

**CABLE DRILL** *See* CHURN DRILL.

**CABLEWAY SCRAPER** *See* SLACKLINE SCRAPER.

**CAISSON** A metal cylinder used to sink prospect shafts in loose ground or in the presence of a large quantity of water. Caissons are usually provided in sets of four or more telescoping units.

**CALICHE** A brown or white material commonly found as a subsoil deposit in arid or semi-arid climates and composed largely of calcium carbonate. It is usually encountered in desert placers where its cementing effect adversely affects the mining and washing processes.

**CANNON CONCENTRATOR** *See* PINCHED SLUICE.

**CAPPING** Volcanic flow materials or agglomerates that cover and in some cases conceal underlying auriferous gravels. Commonly found associated with Tertiary channels in California's Sierra Nevada region. Also called CAP ROCK.

**CASING** Steel tubing or pipe used to case a drill hole. In placer sampling it is usually driven into the formation ahead of the drill bit and when so used is commonly called a DRIVE PIPE.

**CASING FACTOR** The depth to which a churn drill casing must be driven to take in a sample volume of 1 $yd^3$. For example, a standard 6-in drive pipe equipped with a new 7½-in drive shoe would be driven 88 ft to cut out a theoretical volume of 1 $yd^3$. This is sometimes called the PIPE FACTOR, but it is most commonly known as the DRIVE SHOE FACTOR. *See* RADFORD FACTOR.

**CEMENT** The material that binds together the sand and gravel particles in an indurated placer or other formation. The cementing material can be calcareous, siliceous, or ferruginous. Also used when referring to the hardened formations as a whole. In some cases, cemented gravels must be milled to release their gold content.

**CEMENT CHANNEL** A channel depression completely filled with lava, no auriferous gravel (Dunn, 1888).

**CHALK** Volcanic tuff or ash, largely rhyolitic in composition, is commonly found as intraformational strata or masses in Tertiary channels of California's Sierra Nevada region. The whiter, fine-grained and homogeneous beds are locally called chalk. Note that this differs from usual geologic usage where chalk is commonly thought of as fine-grained calcite.

**CHANNEL** A stream-eroded depression in the bedrock, ordinarily filled with gravel. *See* TERTIARY CHANNELS.

**CHURN DRILL** A portable drilling machine arranged to successively raise and drop a heavy string of tools suspended from a drill line. By means of the successive blows, the formation is chopped up and the hole deepened. The type of churn drill designed for placer sampling is often referred to as a KEYSTONE DRILL or PLACER DRILL. A hand-powered type used extensively in South America is known as a WARD DRILL.

**CLAIM** *See* MINING CLAIM.

**CLAY** A natural material with plastic properties and a composition of very fine grain size (<0.005 mm). It tends to act as a malleable bonding agent between gravel particles and encapsulates gold, which makes recovery difficult. Some clays resist wetting and will separate and not wash.

**CLEAN-UP** 1. The operation of collecting the gold or other valuable material from the recovery system of a dredge, hydraulic mine, or other placer operation. 2. The valuable material resulting from a clean-up.

**COARSE GOLD** The word "coarse," when applied to gold, is relative and is not uniformly applied. Some operators consider coarse gold to be that which remains on a 10-mesh screen. Others consider individual particles weighing 10 mg or more to be coarse gold. Some apply the term COARSE GOLD to any particle that is relatively thick as compared to its diameter and can be easily picked up with the fingers.

**COBBLE** A smoothly rounded stone, larger than a pebble and smaller than a boulder (Fay, 1920).

**COCOA MATTING** A heavy, coarsely woven fabric made of jute-like material and commonly placed on the bottom of a sluice to aid in saving fine gold.

**COLLOIDAL GOLD** Extremely fine particles of gold. In a true colloid, the individual particles are of almost molecular dimensions.

**COLLUVIAL** Consisting of alluvium in part and also containing angular fragments of the original rocks (Fay, 1920).

**COLOR** A particle of metallic gold found in the prospector's pan after a sample of earth has been washed. Prospectors say, "The dirt gave me so many colors to the pan" (Fay, 1920).

**CONCENTRATE** 1. (verb) To separate a metal or mineral from its ore or from less valuable material. 2. (noun) The product of concentration.

**CONCENTRATION** The removal by mechanical means of the lighter and less valuable portions of ore (Fay, 1920).

**CONFLUENCE** A junction or flowing together of streams; the place where streams meet (Fay, 1920).

**CONGLOMERATE** Rounded waterworn fragments of rock or pebbles, cemented together by another mineral substance (AGI, 1962).

**CORE** *See* DRILL CORE.

**CORE FACTOR** In churn drilling, when the casing is driven downward ahead of the drill bit, it should take in a cylinder of gravel having a diameter equal to the effective diameter (cutting edge) of the drive shoe. If the effective diameter of the shoe were the same as the inside diameter of the casing, a 1-ft drive would produce a 1-ft core rise inside the casing, but this is not so. Take for example a standard 6-in casing equipped with a new 7½-in drive shoe. The effective area of the shoe is 44.17 square inches, while that of the casing is about 26 square inches. As a result, when driven, the core should rise 44.17/26 = 1.7, or in other words, there should be a 1.7-ft core rise inside the casing for each foot of drive. Here, the CORE FACTOR is 1.7. The core factor will, of course, vary according to the combination of casing and drive shoe used, and it will vary with the amount of wear on a given shoe. The core rise per foot of drive is less commonly referred to as the SHOE FACTOR, but use of this term here invites risk of confusing it with other factors or terminology. *See* DRIVE SHOE FACTOR; PIPE FACTOR; CASING FACTOR; DRILL FACTOR; and RADFORD FACTOR.

**CORE RISE** The measured length of the cylinder of gravel entering a churn drill casing as it is driven downward. For example: a standard 6-in casing fitted with a 7½-in drive shoe should produce a core rise of 1.7 ft per foot of drive. The difference between the actual core rise and the theoretical rise is sometimes used as a factor for adjusting drill hole sample values.

**CORRECTED VALUE** *See* ADJUSTED VALUE.

**CRADLE** *See* ROCKER.

**CREEK PLACER** Gravel deposits in the beds and intermediate flood plains of small streams (Brooks, 1908).

**CREVICING** A small-scale mining method in which the miner removes detrital material from cracks and crevices in the bedrock, usually by means of pry bars and long-handled spoons, and washes the material to recover its gold content.

**CRIBBING** Close timbering as the lining of a shaft (Fay, 1920). In placer work, cribbing may be needed to support the walls of shafts or test pits put down in loose or wet ground.

**DEBRIS** The tailings from hydraulic mines.

**DEEP LEAD** (pronounced leed) A gold-bearing alluvial deposit buried below a considerable thickness of soil, lava, or other barren material. *See* TERTIARY CHANNEL.

**DEFLATION** This term is most often used to describe the process through which wind and sheetwash remove fine material on the earth's surface and leave behind only large rocks. It is commonly seen in deserts where deflation results in a tightly fitting desert pavement of flat rocks. In evaluation of placer deposits, deflation applies largely to residual and lag deposits and refers to the process through which gold particles are left behind as water washes away lighter materials. The elevation of the surface is gradually lowered as the lighter particles wash away and the gold is left. In the Bradshaw Mountains of Arizona, multiple episodes of uplift and deflation have resulted in small, isolated residual and lag deposits of very high value.

**DESERT PLACER** *See* DRY PLACER.

**DETRITUS** A general name for incoherent sediments produced by the wear and tear of rocks through the various geological agencies. The name is from the Latin for "worn" rock waste (Fay, 1920). A deposit of such material.

**DILUTION FACTOR** An estimate of barren overburden that mixed with the placer sample during collection. It is most commonly used during bulk sampling with heavy equipment.

**DIP BOX** A modification of the sluice box used for small-scale mining where water is scarce. It generally consists of a short sluice made of 1- x 12-in lumber and stands on legs arranged to provide a steep slope. The gold-bearing material is washed in batches by first shoveling it into the upper end of the dip box and then pouring water over it, usually from a dipper.

**DIRT** A miner's term for auriferous gravel or for the material being worked. *See* PAY DIRT.

**DISCHARGE HEAD** The vertical distance from the center of a pump to the center of the discharge outlet where the water is delivered, to which must be added the loss due to friction of the water in the discharge pipe.

**DISCOVERY** The finding of a valuable mineral deposit in place upon a mining claim. Although "discovery" and "valuable," as they relate to mining claims have not been defined by statute, a long history of court decisions have held that in order for a location to be valid, there must be a discovery of mineral within the limits of the claim and the discovery must be such as would justify a person of ordinary prudence in the further expenditure of labor and money, with reasonable prospect of success in developing a profitable mine. In some decisions the word "valuable" is interchanged with "profitable."

**DISCOVERY CLAIM** (Alaska) A claim covering the initial discovery on a creek. Subsequent claims are commonly designated as one above, two above, three above, one below, two below, depending on their position in relation to the discovery claim.

**DOODLEBUG** 1. Miners' term for a dragline dredge. 2. A divining rod or similar device supposedly useful for locating gold or other valuable minerals. *See* DRAGLINE DREDGE.

**DRAGLINE** A power shovel equipped with a long boom and a heavy digging bucket that is suspended from a hoisting line and is pulled toward the machine by means of a "drag" line. By manipulating the two lines (wire ropes), the bucket can be caused to dig, carry, or dump the excavated material. Such a machine is more properly called a dragline excavator. *See* DRAGLINE DREDGE.

**DRAGLINE DREDGE** A dragline dredge consists of two units: a self-propelled power shovel equipped with a dragline bucket, and a floating washing plant which is similar to, but usually smaller than, that of a bucket-line dredge. The washing unit contains a hopper for receiving gravel dug by the dragline, a revolving screen, riffled sluices or other gold-saving equipment, and a tailings stacker. Dragline dredges are generally employed to mine relatively small, shallow deposits that are too small to amortize a bucket-line dredge.

**DREDGE** A machine, operated by power, and usually mounted on a flat-bottomed hull provided with the equipment necessary to dig, process, and dispose of alluvial or other unconsolidated materials of a type found at the bottom of rivers or in certain terrestrial and offshore deposits. *See* BUCKET-LINE DREDGE; DRAGLINE DREDGE; JET DREDGE; SUCTION DREDGE.

**DREDGE SECTION** The depth of gravel, or a particular vertical section within a placer deposit, that will pay to mine by dredging.

**DRIFT** (geology) Any rock material, such as boulders, till, gravel, sand, or clay, transported by a glacier and deposited by or from the ice or by or in water derived from the melting of the ice (Fay, 1920).

**DRIFT** (mining) 1. A sub-tunnel running from the main tunnel to prospect for the pay lead. 2. A sub-tunnel run from the main tunnel across the pay lead to block out the ground and to facilitate its working. 3. Generally, a sub-tunnel (Dunn, 1888).

**DRIFT MINING** A method of mining gold-bearing gravel by means of drifts, shafts, or other underground openings, as distinguished from surface methods for placer mining.

**DRILL** *See* CHURN DRILL.

**DRILL CORE** A cylindrical core of sand and gravel forced upward into the drill casing as the casing or "drive pipe" is forced into the deposit, usually ahead of the drill bit. *See* CORE RISE.

**DRILL FACTOR** A figure used to designate the effective area of a drive shoe used in placer sampling. For example: a new, 7½-in drive shoe has an open area of 0.306 $ft^2$, but to allow for wear and other variables, some engineers use a lesser figure (commonly 0.27) in their value calculations. The figure so used is referred to as the DRILL FACTOR. *See* RADFORD FACTOR; CORE FACTOR; VOLUME FACTOR; and DRIVE SHOE FACTOR.

**DRILL LOG** The record of a drill hole, usually recorded on a prepared form as the work progresses. The usual placer log, in addition to showing the drilling progress, type of material penetrated, its mineral content, etc., will show the type and size of equipment used, personnel employed, cause of delays, and other details of the work. A complete log will also show the essential calculations and all factors used in arriving at the reported value.

**DRIVE PIPE** *See* CASING.

**DRIVE SHOE** A hardened steel protective shoe attached to the lower end of a drive pipe or casing. The drive shoe is usually slightly larger in diameter than the casing and is provided with a beveled cutting edge. *See* CASING.

**DRIVE SHOE FACTOR** The depth to which a churn drill casing must be driven to take in a sample volume of 1 $yd^3$. For example, a standard 6-in drive pipe equipped with a new, 7½-in drive shoe would be driven 88 ft to cut out a theoret-

ical sample volume of 1 $yd^3$. This is less commonly called the PIPE FACTOR or CASING FACTOR. *See* RADFORD FACTOR.

**DRY DIGGINGS** In the 1850s, placers in or along the banks of California's rivers were known as "wet diggings," and those in the dry ravines adjacent to the rivers were referred to as "dry diggings." Compare with DRY PLACER.

**DRY PLACERS** Placers in arid or semi-arid regions, or generally where surface water is not available.

**DRY WASHER** A device for recovering gold or other heavy minerals from dry alluvial material without the use of water. The typical dry washer is a small, hand-powered machine employing a sloping riffle board and a bellows or blower arrangement. The bottom of the riffle board is made of some porous material such as heavy cloth. Puffs of air forced up through the bottom by the bellows or blower cause the lighter materials to hop over the riffles and work their way through the machine, while the gold or other heavy materials lodge behind the riffle ban.

**DRY WASHING** The extraction of gold or other minerals from dry sand and gravel by the use of machines in which air is employed as a separating medium.

**DRYLAND DREDGE** A mechanical washing plant, sometimes of appreciable size, designed to follow a dragline or other excavator as the mining cut advances. Some are equipped with trommel-type revolving screens and rock stackers, and are mounted on crawler tracks.

**DUMP** 1. The fall immediately below a hydraulic mine outlet and, in particular, the area available for tailings storage. 2. A specially prepared place outside a drift mine, usually near the portal, where the pay gravel is deposited in preparation for washing. 3. A pile or heap of material, usually waste, extracted from a mine.

**DUST** *See* GOLD DUST.

**DUTY** 1. A measure of the effectiveness of water employed in hydraulic mining, usually expressed as the number of cubic yards of gravel washed per miner's inch per day (M.I.D.). The duty varies with the coarseness of gravel, height of bank, grade, available head, etc., usually varying from 1 to 7 $yd^3$ per miner's inch per 24 hours. 2. The effectiveness of water generally.

**ELECTROSTATIC SEPARATOR** A device employing charged fields with little or no current flow used to extract or separate the component minerals of sands or heavy mineral concentrates. Generally speaking, electrostatic separators do not make sharp separations, and they are sensitive to humidity, temperature, and other variables. Electrostatic separators have not found wide application in placer mining. Compare with HIGH TENSION SEPARATOR.

**ELEVATED SLUICE** *See* TRESTLE SLUICE.

**ELEVATOR** A device for ejecting gravel or tailings from a hydraulic mine pit. *See* HYDRAULIC ELEVATOR and RUBEL ELEVATOR.

**ELUVIAL DEPOSIT** *See* ELUVIUM.

**ELUVIUM** Loose material resulting from decomposition of rock. Eluvial material may have slumped or washed downhill for a short distance, but it has not been transported by a stream.

**EMPIRE DRILL** *See* BANKA DRILL.

**EOCENE** One of the earliest of the epochs into which the Tertiary period is divided; also the series of strata (and auriferous gravels) deposited at that time. Specifi-

cally, an epoch of the Tertiary between the Paleocene and Oligocene. The time period about 37 to 58 million years ago.

**EROSION CYCLES** The Earth's erosional land forms develop in successive stages that can be divided into three broad categories—youth, maturity, and old age. Youthful land forms in the erosion cycle are featured by steep, narrow, V-shaped canyons and fast-cutting streams. In time, as the valleys deepen, they become wider and have gentler slopes. In early maturity they are roughly U-shaped instead of V-shaped. In late maturity down cutting slows, and conspicuous flats develop. Old age is marked by wide, flat valleys or peneplains, over which sluggish streams follow meandering courses. The mature stage is most favorable for the development of extensive placers.

**EXPANDED METAL** (Expanded-metal lath) A type of punched-metal screen. The style commonly used in placer mining, for saving fine gold, consists of a latticework of diamond-shaped openings (about ¾ x 1½ in) separated by raised metal strands that have a decided slope in one direction. When installed as riffles, with this slope leaning downstream, eddies form beneath the overhangs, thus creating conditions well suited for the saving of fine gold. When used as riffles, expanded metal is generally placed over cocoa matting or similar material. A flat-lying style of expanded metal (without overhangs) does not perform as well for this use.

**FALSE BEDROCK** A hard or relatively tight formation within a placer deposit, at some distance above true bedrock, upon which gold concentrations are sometimes found. Clay, volcanic ash, caliche, or "tight" gravel formations can serve as false bedrocks. A deposit may have gold concentrations on one or more false bedrocks, with or without a concentration on true bedrock.

**FANNING CONCENTRATOR** *See* PINCHED SLUICE.

**FINE GOLD** 1. Pure gold, i.e., gold of 1000 fineness. 2. Gold occurring in small particles such as those that would pass a 20-mesh screen but remain on 40-mesh.

**FINENESS** The proportion of pure gold in bullion or in a natural alloy expressed in parts per thousand. Natural gold is not found in pure form; it contains varying proportions of silver, copper, and other substances. For example, a piece of natural gold containing 150 parts of silver and 50 parts of copper per thousand and the remainder pure gold would be 800 fine.

**FINES** 1. The sand or other small components of a placer deposit. 2. The material passing through a screen during washing or other processing steps of a placer operation.

**FIRE ASSAY** The assaying of metallic ores, usually gold and silver, by methods requiring furnace heat (Fay, 1920). Fire assaying, in essence, is a miniature smelting process that recovers and reports the total gold content of the assay sample, including the gold that is combined with other elements or mechanically locked in the ore particles. Consequently, the gold value indicated by fire assay is not necessarily recoverable by placer methods. For this and other reasons, the gold content of placer material is not normally determined by fire assay. *See* FREE GOLD ASSAY.

**FLAKY GOLD** Very thin scales or pieces of gold.

**FLASK** The unit of measurement for buying and selling mercury (quicksilver). A standard iron flask contains 76 lbs of mercury.

**FLAT** An essentially level gravel bar or deposit along the banks of a river.

**FLOAT** A term much used among miners and geologists for pieces of ore or rock which have fallen from veins or strata, or have been separated from the parent vein or strata by weathering agencies. Not usually applied to stream gravels (Fay, 1920).

**FLOAT GOLD** Flour gold. Particles of gold so small and thin that they float on and are liable to be carried off by the water (Fay, 1920). *See* FLOOD GOLD.

**FLOOD GOLD** Fine-size gold flakes carried or redistributed by flood waters and deposited on gravel bars as the flood waters recede. Flood gold sometimes forms superficial concentrations near the upstream end of accretion bars. *See* FLOAT GOLD.

**FLOOD PLAIN** The portion of a river valley adjacent to the river channel that is built of sediments during the present regimen of the stream and is covered with water when the river overflows its banks at flood stages (AGI, 1962).

**FLOUR GOLD** The finest gold dust, much of which will float on water (Fay, 1920). Flour gold, such as that found along the Snake River in Idaho, commonly runs 3 million colors to the ounce.

**FLOURED MERCURY (QUICKSILVER)** The finely granulated condition of quicksilver, produced to a greater or less extent by its agitation during the amalgamation process. The coating of quicksilver with what appears to be a thin film of some sulfide, so that when it is separated into globules, these refuse to reunite. Also called "sickening" and "flouring" (Fay, 1920).

**FLUVIAL** Of or pertaining to rivers; produced by river action, as a fluvial plain (Fay, 1920).

**FLUVIATILE** Caused or produced by the action of a river; fluvial (Fay, 1920).

**FLUVIOGLACIAL** Produced by streams that have their source in glacial ice (Fay, 1920). *See* GLACIOFLUVIAL.

**FLUVIO-MARINE** Formed by the joint action of a river and the sea, as in the deposits at the mouths of rivers (Fay, 1920).

**FOOL'S GOLD** A substance that superficially resembles gold; usually pyrite, a sulfide of iron, $FeS_2$; also applied to biotite mica, which is often mistakenly identified as fine or flour gold.

**FREE GOLD** Gold uncombined with other substances. Placer gold (Fay, 1920).

**FREE GOLD ASSAY** A procedure carried out to determine the free gold content of an ore. In the case of placer material, a procedure to determine the amount of gold recoverable by gravity concentration and amalgamation.

**FREE-WASH GRAVEL** Gravel that readily disintegrates and washes in a sluice. Loose, clay-free gravels such as those found in accretion bars are generally free-wash gravels.

**GIANT** *See also* HYDRAULIC GIANT and INTELLIGIANT.

**GLACIAL** Pertaining to, characteristic of, produced or deposited by, or derived from a glacier (AGI, 1962).

**GLACIOFLUVIAL** Of, pertaining to, produced by, or resulting from combined glacier action and river action (Fay, 1962). *See* FLUVIOGLACIAL.

**GOLD DUST** A term once commonly applied to placer gold, particularly gold in the form of small colors.

**GOLD PAN** *See* PAN.

**GOLD-SAVING TABLE** The sluices used aboard a dredge are customarily called gold-saving tables, rather than sluice boxes.

**GRADE** 1. The amount of fall or inclination from horizontal in ditches, flumes, or sluices; usually measured in inches fall per foot of length or inches fall per section of sluice. 2. The slope of a land or bedrock surface, usually measured in percentage. A 1 percent grade is equivalent to a rise or fall of 1 ft per 100 ft horizontally. 3. The slope of a stream or the surface over which the water flows, usually measured in feet per mile. Streams having a grade of about 30 ft per mile favor the accumulation of placers, particularly where a fair balance between transportation and deposition is maintained for a long time. 4. The relative value or tenor of an ore, or of a mineral product.

**GRADED STREAM** A stream in equilibrium; that is, a stream or a section of a stream that maintains a balance between material eroded from and deposited in its channel.

**GRAIN** A unit of weight equal to 0.0648 parts of a gram, 0.04167 parts of a pennyweight, or 0.002083 parts of a troy ounce. There are 480 grains in a troy ounce. A grain of fine gold has a value of 7.29 cents (@$35/oz).

**GRAM** A unit of weight in the metric system equal to 15.432 grains, 0.643 pennyweight, or 0.03215 troy oz. There are 31.103 g in a troy ounce. A gram of fine gold has a value of $1.12 (@ $35/oz) or $12.86 (@ $400/oz).

**GRAVEL** A comprehensive term applied to the water-worn mass of detrital material making up a placer deposit. Placer gravels are sometimes arbitrarily described as “fine” gravel, “heavy” (large) gravel, “boulder” gravel, and so on.

**GRAVEL MINE** A placer mine; a body of sand or gravel containing particles of gold (Fay, 1920).

**GRAVEL PLAIN PLACERS** Placers found in gravel plains formed where a river canyon flattens and widens or, more often, where it enters a wide, low-gradient valley.

**GRIZZLY** An iron grating that serves as a heavy-duty screen to prevent large rocks or boulders from entering a sluice or other recovery equipment.

**GROUND SLUICING** A mining method in which the gravel is excavated by water not under pressure. A natural or artificial water channel is used to start the operation, and while a stream of water is directed through the channel or cut, the adjacent gravel banks are brought down by picking at the base of the bank and by directing the water flow so as to undercut the bank and aid in its caving. Sluice boxes may or may not be used. Where not used, the gold is allowed to accumulate on the bedrock awaiting subsequent clean-up. A substantial water flow and adequate bedrock grade are necessary. *See* BOOMING.

**GUTTER** The lowest portion of an alluvial deposit; commonly a relatively narrow depression or trough in the bedrock. In some placers the pay streak is largely confined to a narrow streak or "gutter."

**HAND DRILL** *See* WARD DRILL; BANKA DRILL; and EMPIRE DRILL.

**HEAD** 1. A measure of (water) pressure. 2. The height of a column of water used for hydraulicking. For example, a hydraulic mine in which the point of water discharge is 200 vertical ft below the intake point (of the pipe) would be said to be working with a 200-ft head.

**HEAVY GOLD** 1. (noun) Gold in compact pieces that appear to weigh heavy in proportion to their size. 2. (noun) Rounded "shotty" or "nuggety" gold. 3. (verb) To selectively mine a deposit so as to remove only relatively rich portions and leave lower grades behind.

**HEAVY MINERALS** The accessory detrital minerals of a sedimentary rock of high specific gravity (AGI, 1962). The black sand concentrate common to placers would more properly be called a "heavy mineral" concentrate.

**HIGH-GRADE** 1. (noun) Rich ore. 2. (verb) To steal or pilfer ore or gold, as from a mine by a miner (Fay, 1920).

**HIGH-GRADER** One who steals and sells or otherwise disposes of high-grade or specimen ores (Fay, 1920).

**HIGH TENSION SEPARATOR** A machine essentially consisting of a rotating drum upon which a thin layer of dry sand or mineral grains is fed and an electrode suspended above the rotating drum, or rotor. The electrode furnishes a high-voltage discharge at high current flow. High tension separators employ a high rate of electrical discharge to separate various minerals according to their relative conductivity. Some are pinned to the rotor, while others are attracted toward the electrode, with a resultant "lifting" effect. The pinning and lifting effects, imparted in varying degrees to different minerals, flatten or heighten their respective trajectories as they leave the rotor. Adjustable splitters placed in the trajectory are employed to cut selected minerals or groups of minerals from the stratified stream of material. High tension separators differ from electrostatic separators in that the latter employ charged fields with little or no current flow. High tension separators are extensively used for separating heavy minerals recovered from beach sands, monazite placers, etc.

**HORN SPOON** *See* SPOON.

**HUMPHREY'S SPIRAL** *See* SPIRAL CONCENTRATOR.

**HUNGARIAN RIFFLE** A riffle in a sluice box made from angle iron. The newer designs utilize a 1- x 1-in set leaving 15° up the box with the top of the bar 15 percent off of parallel to the box floor. The open side always points down gradient. *See* RIFFLE.

**HYDRAULIC DREDGE** A dredge in which the material to be processed is excavated and elevated from the bottom of a stream or pond by means of a pump or a water-powered ejector. Large hydraulic dredges may be equipped with a digging ladder that carries the suction pipe and a motor-driven cutter head arranged to chop up or otherwise loosen material directly in front of the intake pipe. Dredges in this configuration employ a deck-mounted suction pump, and may carry the mineral recovery equipment on board the dredge or, more commonly, may transport the excavated material by means of a pipeline to a recovery plant mounted on independent barges or on the shore. *See* JET DREDGE and BUCKET-LINE DREDGE.

**HYDRAULIC ELEVATOR** A near-vertical pipe employed in hydraulic mining to raise excavated material from the working place to an elevated sluice or to a disposal area by means of a high-pressure water jet inducing a strong upward current in the elevator pipe. *See* RUBEL ELEVATOR.

**HYDRAULIC GIANT** The nozzle assembly used in hydraulic mining. The giant is provided with a swivel that enables it to be swung in a horizontal plane, and it may be elevated or depressed in a vertical plane. Nozzle sizes range from 1 to 10 in. in diameter, and the larger sizes are provided with a deflector, which enables them to be moved with little effort. In California, giants discharging as much as 15,000 gal per minute in a single stream at a nozzle pressure of over 200 lbs per

square inch have been used. The giant is also known as a "Monitor." Both terms stem from manufacturer's trade names. *See* INTELLIGIANT.

**HYDRAULIC MINING** A method of mining in which a bank of gold-bearing earth or gravel is washed away by a powerful jet of water and carried into sluices, where the gold separates from the earth by its specific gravity (Fay, 1920).

**HYDRAULIC MONITOR** *See* HYDRAULIC GIANT.

**HYDRAULICKING** Mining by the hydraulic method. (Note spelling).

**INCHES OF WATER** A common expression denoting the quantity of water (in miner's inches) available or being used in a placer operation. *See* MINER'S INCH.

**INDEXING** Method of updating economic information based on cost indices.

**INDICATED VALUE** The value of a placer sample derived by formula before making adjustments to compensate for excess or deficient core rise, in the case of churn drilling, or before applying shaft factors, boulder factors, or other empirical corrections. *See* ADJUSTED VALUE.

**INLET** The point where a channel is cut off by a ravine or canyon on the upstream end (Dunn, 1880). Usually applied to buried channels. Compare with BREAKOUT and OUTLET.

**INTELLIGIANT** The trade name for a hydraulic giant that is provided with water-powered piston and cylinder arrangements to control its vertical and horizontal traverses. Some models can be rigged for automatic operation and can run unattended in a preset arc or pattern. *See* HYDRAULIC GIANT.

**IRON SAND** 1. Magnetite or ilmenite-rich sand. 2. Black sand concentrate containing an abundance of magnetite.

**JET DREDGE** A form of hydraulic dredge. Jet dredging equipment may range from a simple, self-contained pipe-like venturi containing riffles that is carried by a diver and operates entirely underwater to larger and more elaborate surface units carried on inflated rubber tubes or Styrofoam floats. These devices, operated by one or two men, are similar in two ways: (1) they rely on a water jet and venturi effect to pick up unconsolidated stream bottom materials and carry them to a gold recovery device, usually riffles, and (2) the suction intake is normally handheld and guided by a diver working on the stream bottom. The typical jet dredge entails a small or modest capital outlay and is typically used for recreational mining. *See* HYDRAULIC DREDGE.

**JET DRILL** A churn-type drill employing a string of reciprocal hollow rods equipped with a drill bit. Water is pumped through the rods and discharged through an orifice near the bit. Cuttings resulting from the chopping action of the bit are carried to the surface by wash water rising between the drill rods and casing. Rods are added as the hole deepens; thus the drill cable does not go down the hole as would be the case in conventional churn drilling. Jet drills are well-suited to sampling low-value minerals, such as ilmenite, that occur in beach deposits.

**JIG** A machine in which heavy minerals are separated from sand or gangue minerals on a screen in water by the pulsation of water through the screen. Where the heavy mineral is larger than the screen openings, a concentrate bed forms on top of the screen. Where the heavy mineral particles are smaller than the screen openings, a fine-size concentrate is collected in a hutch beneath the screen.

**JIG BED** The agent or media in a jig through which the water pulses during the concentration process. This agent often consists of the heavy minerals in the ore and

behaves in some respects like a dense fluid. The pulsation of the water or the motion of the screen keeps the bed open, or in suspension, during part of the cycle so that heavy minerals entering the jig can settle into the bed. Lighter minerals cannot penetrate the jig bed and so are forced to remain in the upper part of the jig and eventually discharge over the top. Other agents in use are lead shot, iron punchings, iron shot, pyrite, magnetite, and weighted ceramic balls.

**JIG HUTCH** The lower compartment of an ore-dressing jig, below the jig bed screen. It collects the smaller, heavier mineral particles for further processing.

**KEYSTONE CONSTANT** *See* RADFORD FACTOR.

**KEYSTONE DRILL** *See* CHURN DRILL.

**KNUDSEN BOWL** *See* AINLAY BOWL.

**LACUSTRINE DEPOSITS** Deposits formed in the bottom of lakes (Fay, 1920). Compare with LAKEBED PLACERS.

**LAG DEPOSITS** Placer deposits formed by deflation rather than sedimentation.

**LAKEBED PLACERS** Placers accumulated in the beds of present or ancient lakes that were generally formed by landslides or glacial damming (Brooks, 1908). It should be noted that a lakebed (or lake-bottom) placer might actually be a drowned stream placer.

**LAVA** As used by a placer miner, may designate any solidified volcanic rock, including volcanic agglomerates.

**LEAD** (pronounced leed) Deeply buried placer gravel, where rich enough to work and particularly when in a well-defined bed, is often termed the "lead" or "pay lead."

**LIGHT GOLD** Gold that is in very thin scales or flakes or in pieces that look large as compared to their weight. *See* FLOOD GOLD.

**LITTORAL** Pertaining to the shore of a lake, sea, or ocean.

**LOCATION** *See* MINING CLAIM.

**LONG TOM** 1. A small sluice-type gold washer widely used in California during the 1850s and 1860s. The early long tom was built in two sections: a washing box equipped with a perforated plate to screen out the rocks, followed by a short sluice containing riffles. 2. A short auxiliary sluice used aboard a dredge to further reduce concentrate taken from the dredge riffles at clean-up time. 3. A short sluice used to wash placer samples.

**LOOSE CUBIC YARD** All reserves and resources are reported in bank cubic yards, but production and costs are reported as loose cubic yards (lcy). Loose cubic yards are calculated as the reserve plus the swell or void spaces. It is reported in lcy units.

**LOW-GRADE** A term applied to ores relatively poor in the metal for which they are mined; lean ore (Fay, 1920).

**MAGNETIC SEPARATOR** A device employing a strong magnetic field to remove magnetic materials from a sand or a concentrate, or to selectively remove or separate their constituent minerals. Magnetic separators are commonly used in conjunction with high tension separators to process the heavy mineral concentrates obtained from beach sands, monazite placers, tin placers, and so on.

**MARINE MINING** The exploitation of sea-bottom mineral deposits, including placers. *See* MARINE PLACER.

**MARINE PLACER** A deposit of placer-type minerals on the ocean or sea bottom beyond the low-tide line, as distinguished from beach placers. Some marine plac-

ers may contain material related to beach deposits formed during periods of low sea level. Others may contain stream-type placers or mineral concentrations formed on land and later submerged by a lowering of the coastal region.

**MATURITY** (*As in* mature valley). *See* EROSION CYCLES.

**MEANDER** One of a series of somewhat regular and loop-like bends in the course of a stream, developed when the stream is flowing at grade through lateral shifting of its course toward the convex sides of the original curves (Fay, 1920).

**MEDIUM-SIZE GOLD** Gold of an approximate size that will pass through a 10-mesh screen and remain on a 20-mesh screen. Compare with COARSE GOLD; *see also* FINE GOLD.

**MERCURY** A heavy, silver-white liquid metallic element, useful in placer mining where its chemical affinity for gold is used to help detain gold in a sluice box. Mercury placed in the riffles forms a gold amalgam, which is removed at the time of clean-up and then retorted to recover the gold. The miners' term for mercury is "quicksilver" or simply "quick." Symbol, Hg; specific gravity, 13.54.

**MILLIGRAM** One-thousandth of a gram. As a matter of convenience, the milligram is widely used as the unit for reporting gold weights in placer samples. There are 31,103 mg in a troy ounce. With gold at $350 per troy ounce, 1 mg of fine gold is worth 01.12 cents, and 1 mg of ordinary placer gold is worth about 1.0 cent.

**MINER'S INCH** A unit of water measurement. Originally it represented the quantity of water that will escape from a 1-in square aperture through a 2-in plank, with a steady flow of water standing 6 in above the top of the escape aperture. The miner's inch is now defined by statute in various states.

1 second-foot (cubic foot per second) = 40 miner's inches in Arizona, California, Montana, Oregon, and Alaska.

= 50 miner's inches in Idaho, Nevada, New Mexico, and Utah.

= 38.4 miner's inches in Colorado.

1 miner's inch equals 11.25 gal per minute when equivalent to 1/40 second-foot.

1 miner's inch equals 9 gal per minute when equivalent to 1/50 second-foot.

**MINER'S PAN** *See* PAN.

**MINER'S SPOON** *See* SPOON.

**MINING CLAIM** That portion of the public mineral lands which a miner, for mining purposes, takes and holds in accordance with the mining laws (Fay, 1920). A mining claim may be validly located and held only after the discovery of a valuable mineral deposit. *See* DISCOVERY.

**MONITOR** *See* HYDRAULIC GIANT.

**MORAINE** An accumulation of debris carried and finally deposited by a glacier. A moraine formed at the lower extremity of a glacier is called a terminal moraine; at the side, a lateral moraine; in the center and parallel with its sides, a medial moraine; and beneath the ice but back from its end or edge, a ground moraine (Fay, 1920). Placer gold is found in some glacial moraines and deposits of reworked morainal material; that is, material reworked by streams. Some have been dredged and worked by other placer methods.

**MOSS MINING** (*Also* mossing) The gathering of moss from the banks of gold-bearing streams for the purpose of burning or washing it to recover its gold content. Under certain conditions, moss or similar vegetation will capture and hold small particles of gold carried downstream by flood waters. *See* FLOOD GOLD.

**MUCK** (Alaska) A permanently frozen overburden associated with placer deposits of the Alaskan Interior. Composed of fine mud, organic matter, and small amounts of volcanic ash, it varies in depth (thickness) from less than 10 ft to 100 ft or more in places. This overburden (muck) must be removed and the underlying gravels thawed before dredging is possible.

**NATIVE GOLD** 1. Metallic gold found naturally in that state. 2. Placer gold.

**NUGGET** 1. A water-worn piece of native gold. The term is restricted to relatively large sizes, not mere "colors" or minute particles. Fragments and lumps of vein gold are not called nuggets because the idea of alluvial origin is implicit (Fay, 1920). 2. Anything larger than about 1 pennyweight or 1 g may be considered a nugget. *See* PEPITA.

**NUGGETY** Like or resembling a nugget; occurring in nuggets; also abounding in nuggets. (Fay, 1920)

**OLD AGE** *See* EROSION CYCLES.

**OUTCROP** The exposure of bedrock or strata projecting through the overlying cover of detritus and soil (AGI, 1962).

**OUTLET** The point where a channel is cut off by a ravine or canyon on the downstream end (Dunn, 1888). Usually applied to buried Tertiary channels. Compare with BREAKOUT and INLET.

**OVERBURDEN** Worthless or low-grade surface material covering a body of useful minerals. The frozen muck covering dredge gravels in the Interior region of Alaska is an example of placer overburden.

**OFFSHORE DEPOSITS** Mineral deposits on the ocean or sea bottom beyond the low-tide line. *See* MARINE PLACER.

**PAN** 1. (noun) A shallow sheet-iron vessel with sloping sides and a flat bottom used for washing auriferous gravel or other materials containing heavy minerals. It is usually referred to as a "gold pan," but is more properly called a "miner's pan." Pans are made in a variety of sizes, but the size generally referred to as "standard" has a diameter of 16 in at the top, 10 in at the bottom, and a depth of 2.5 in. Pans made of copper or provided with a copper bottom are sometimes used for amalgamating gold. 2. (verb) To wash earth, gravel, or other material in a pan to recover gold or other heavy minerals.

**PAN FACTOR** The number of pans of gravel equivalent to a cubic yard in place. Pan factors vary according to the size and shape of the pan, the amount of heaping when filling the pan, and the swell of ground when excavated, as well as other factors. In practice, factors for a 16-in pan range from 150 to 200; a factor of 180 is widely used.

**PANNING** Washing gravel or other material in a miner's pan to recover gold or other heavy minerals.

**PATENT** A document by which the Federal government conveys fee simple title to a mining claim. To obtain a mineral patent, the applicant must, among other things, (1) make a discovery of a valuable mineral deposit, (2) invest $500 in improvements, (3) pay for a boundary survey if lode minerals are applied for, and (4) pay $2.50 per acre for the lands in a placer application, or $5.00 per acre for the lands in a lode application. *See* DISCOVERY. (Note: No new patent applications have been accepted since 1989 through a moratorium enacted by Congress.)

**PAY DIRT** Auriferous gravel rich enough to pay for washing or working (Fay, 1920).

**PAY LEAD** (pronounced leed) Where gravel is found rich enough to work and in a well-defined bed, it is often termed the "pay lead" or "lead." Compare with PAY STREAK.

**PAY STREAK** A limited horizon within a placer deposit, containing a concentration of values or made up of material rich enough to mine. Pay streaks in gold placers are commonly found as more or less well-defined areas on or near bedrock and are commonly narrow, sinuous, and discontinuous. Compare with PAY LEAD.

**PEDIMENT** Gently inclined planate erosion surfaces carved in bedrock and generally veneered with fluvial gravels. They occur between mountain fronts and valley bottoms and commonly form extensive bedrock surfaces over which the erosion products from the retreating mountain fronts are transported to the basins (AGI, 1962).

**PENEPLAIN** A land surface worn down by erosion to a nearly flat or broadly undulating plain; the penultimate stage of old age of the land produced by the forces of erosion (AGI, 1962).

**PENNYWEIGHT** A unit of weight equal to 24 grains, 0.05 troy oz, or 1.5552 g. A pennyweight of fine gold has a value of $1.03, with gold at $20.67 per ounce, or a value of $1.75, with gold at $35.00 per ounce.

**PEPITA** (Spanish) A nugget, usually of small size.

**PERMAFROST** Permanently frozen ground in Alaska, up to 100 or more feet in thickness. *See* MUCK.

**PILOT SLUICE** A small auxiliary sluice operated intermittently aboard a dredge to determine the amount of gold being recovered by the dredge during a given interval of time or from a particular gravel section. The ratio of pilot sluice recovery to dredge recovery is determined for each dredge by empirical means.

**PINCHED SLUICE** A film-type gravity concentrator employing a wedge-shaped trough, tapering to a narrow vertical opening at its discharge end. In use, heavy gravity minerals migrate toward the bottom and are removed from the stratified discharge stream by means of splitters. Pinched sluice-type concentrators are used to remove heavy minerals, such as rutile and ilmenite, from beach sands. The CANNON CONCENTRATOR and FANNING CONCENTRATOR are of this type.

**PIPE CLAY** Miners' term for clays or clay-like materials found in finely laminated beds within the Tertiary gravels of California's Sierra Nevada region. Some may consist of volcanic ash that has fallen into water and taken on a stratified form resembling clay in appearance.

**PIPE FACTOR** The depth to which a churn drill casing must be driven to take in a sample volume of 1 yd$^3$. For example, a standard 6-in drive pipe equipped with a new 7½-in drive shoe would be driven 88 ft to envelop a theoretical volume of 1 yd$^3$. This is sometimes called the CASING FACTOR, but it is most commonly known as the DRIVE SHOE FACTOR. *See* RADFORD FACTOR.

**PIPER** The man operating a hydraulic giant and directing its stream.

**PIPING** Washing gravel with a hydraulic giant.

**PITCH** Used in connection with the bedrock in the channel or rim to express descent (Dunn, 1880).

**PITTING** The act of digging or sinking a pit, as for sampling alluvial deposits (Fay, 1920).

**PLACER** A place where gold is obtained by washing; an alluvial or glacial deposit, as of sand or gravel, containing particles of gold or other valuable mineral. In the United States mining law, mineral deposits, not veins in place, are treated as placers so far as locating, holding, and patenting are concerned (Fay, 1920). The term PLACER applies to ancient gravels as well as to recent deposits and to underground (drift mines) as well as to surface deposits.

**PLACER DEPOSIT** A mass of gravel, sand, or similar material resulting from the crumbling and erosion of solid rocks and containing particles or nuggets of gold, platinum, tin, or other valuable minerals that have been derived from the rocks or veins (Fay, 1920). It is also applied to deposits in now-consolidated rock that originated by placer-forming processes.

**PLACER DRILL** *See* CHURN DRILL.

**PLACER MINING** That form of mining in which the surficial detritus is washed for gold or other valuable minerals. When water under pressure is employed to break down the gravel, the term HYDRAULIC MINING is generally used. There are deposits of detrital material containing gold which lie too deep to be profitably extracted by surface mining and which must be worked by drifting beneath the overlying barren material. To the operations necessary to extract such auriferous material the term DRIFT MINING is applied (Fay, 1920).

**POINT BAR** *See* SKIM BAR.

**POINTS** *See* THAW POINTS.

**PROSPECT DRILL** *See* CHURN DRILL.

**PROSPECTING** 1. Used to qualify work merely intended to discover a pay lead in a drift mine or to locate the channel (Dunn, 1888). 2. (generally) Searching for new deposits. 3. Drilling a known placer deposit to determine its value or delineate a mineable area.

**QUATERNARY GRAVELS** Gravels deposited from the end of the Tertiary period (approximately 1.6 million years ago) to the present time.

**QUICKSILVER** (*Also* quick) *See* MERCURY.

**RADFORD FACTOR** An arbitrary factor used by some engineers in the calculation of drill-hole volumes and, in turn, the drill-hole values. This factor is based on an assumption that due to wear, a 7½-in drive shoe will take in 0.27 $ft^3$ of core per foot of drive, instead of the theoretical 0.306 $ft^3$. In other words, it assumes a core volume of 1/100 $yd^3$ per foot of drive. With this factor, the equation for calculating the drill hole value becomes: value of recovered gold in cents times 100, divided by depth of hole in feet, equals cents per cubic yard. Use of the Radford factor will upgrade the theoretical value by about 12 percent. The Radford factor is sometimes called the keystone constant. When reviewing drill logs or reports, one should take care to determine the factor used. *See* DRILL FACTOR.

**RADIOACTIVE BLACK SAND** A group of dark colored, heavy minerals recovered by placer mining methods and valuable for their contained uranium, thorium, or rare-earth components. They include such minerals as brannerite, euxenite, davidite, betafite, and samarskite. *See* RARE-EARTH MINERALS.

**RARE-EARTH MINERALS** A group of widely distributed but relatively scarce minerals containing rare-earth compounds, usually in combination with uranium, thorium, and other elements. Monazite and other rare-earth minerals are obtained

from placers in Idaho and elsewhere. *See* MONAZITE (in Appendix B) and RADIOACTIVE BLACK SAND.

**R/E** *See* RECOVERY.

**RECOVERY** 1. The amount or value of mineral recovered from a unit volume; in the case of gold placers, expressed as cents per cubic yard. 2. The amount of mineral extracted expressed as a percentage of the total mineral content. 3. In gold dredging, the expression "R over E" (designated R/E) is used to compare actual recovery to expected recovery where "R" represents the actual returns and "E" represents the estimated recoverable value, after allowing for known or expected mining and metallurgical losses, etc. When recovery exceeds the initial estimate, the R/E will be shown as something greater than 100 percent, such as 105 percent, 110 percent, and so on.

**REPRESENTATIVE SAMPLE** *See* SAMPLING.

**RESIDUAL PLACER** Essentially, an in situ enrichment of gold or other heavy mineral caused by weathering and subsequent removal of the lode or other parent material, which leaves the heavier valuable mineral in a somewhat concentrated state. In some cases, a residual placer may be essentially an area of bedrock containing numerous gold-bearing veinlets that have disintegrated by weathering to produce a detrital mantle rich enough to mine. In some parts of California, such areas are known as seam diggings.

**RETORT** A vessel with a long neck used for distilling the quicksilver from amalgam (Fay, 1920).

**RIFFLE** 1. The lining of the bottom of a sluice made of blocks or slats of wood, or stones, arranged in such a manner that chinks are left between them. The whole arrangement at the bottom of the sluice is usually called the "riffles". In smaller gold-saving machines, such as the rocker, the slats of wood nailed across the bottom are called riffle bars, or simply riffles (Fay, 1920). 2. A groove in the bottom of an inclined trough or sluice for arresting gold contained in sands or gravels (Fay, 1920). 3. A shallow extending across the bed of a stream; a rapid of comparatively little fall (AGI, 1962).

**RIM ROCK** (or rim). The bedrock rising to form the boundary of a placer or gravel deposit (Fay, 1920).

**RING SIZE** Particle size such that the piece of ore is too large for screening. It refers to the diameter of the gage or ring that can be slipped over it.

**RIVER-BAR PLACERS** Placers on gravel flats in or adjacent to the beds of large streams (Brooks, 1908).

**RIVER MINING** The mining of part or all of a riverbed after bypassing the stream by means of flumes or tunnels, or by use of wing dams to divert the river from the working area.

**ROCKER** A short, sluice-like trough fitted with transverse curved supports which permit it to be rocked from side to side, and provided with a shallow hopper at its upper end. The hopper bottom consists of a punched metal plate that contains holes about ¼-in or ½-in diameter. This is for the purpose of holding back the larger rocks that, after washing, are discarded. A flow of water, aided by the rocking motion, carries the fine material down the trough where the gold or other heavy minerals are caught by riffles. Rockers are generally operated by hand, but large, power-driven rockers are sometimes employed. When washing churn drill samples, rockers are often used

without riffles, with the recovery being made on the smooth wooden bottom much in the manner of panning. CRADLE is an obsolete term for rocker.

**ROCKING** The process of washing sand or gravel in a rocker.

**ROUGH GOLD** Gold that has not been appreciably worn or smoothed by movement and abrasion. It may be more angular than rounded and may have included or attached quartz particles. As a rule, rough gold is found near its place of origin.

**RUBEL ELEVATOR** (pronounced roo-bull) A form of elevator used in hydraulic mines, particularly those having insufficient bedrock grade for effective tailings disposal. It is essentially a large, inclined flume through which gravel or tailings are driven by a strong water jet furnished by a hydraulic giant. A grizzly removes the fines for treatment in conventional sluices as the larger rocks are discharged from the upper end.

**RUSTY GOLD** Free gold that does not readily amalgamate, the particles being covered with a siliceous film, thin coating of oxide of iron or manganese, etc. (Fay, 1920).

**SALTING** 1. Intentional salting: the surreptitious placing of gold or other valuable material in a working place or in a sample to make it appear rich in minerals for fraudulent purposes. 2. Unintentional or innocent salting: the unintentional or accidental enrichment of a sample through erroneous procedure or carelessness, without intent to defraud.

**SAMPLE** A portion of the ore systematically taken, by which its quality is to be judged (Fay, 1920).

**SAMPLING** Cutting a representative part of an ore deposit, which should truly represent its average value. Honest sampling requires good judgment and practical experience (Fay, 1920). Parenthetically, it should be noted that in the case of gold placers, the high unit value of gold, its extreme dilution within the gravel mass, and its typically erratic distribution are factors that, individually or combined, make it virtually impossible to obtain a truly representative sample. To this extent, the usual definitions of sampling do not apply to gold placers.

**SAND PUMP** A special plunger-type vacuum pump used to remove the chopped-up drill core from a churn drill hole.

**SAUERMAN EXCAVATOR** *See* SLACKLINE SCRAPER.

**SCALY GOLD** Small, rounded, flattened gold particles that are usually quite thin in proportion to their diameter.

**SCHIST** A crystalline rock that can be readily split or cleaved due to a foliated or parallel structure (Fay, 1920). Schist, because of its rough, platy structure, generally makes an excellent gold catcher when streams cross it at near right angles to the cleavage.

**SCHISTOSE** Characteristic of, resembling, pertaining to, or having the nature of schist (Fay, 1920).

**SEABEACH PLACER** *See* BEACH PLACER.

**SEAM DIGGINGS** (California) Residual deposits consisting of decomposed bedrock filled with irregular swarms of quartz containing gold. In California, seam diggings have been worked by the hydraulic method.

**SECOND-FOOT** A unit of water measurement equivalent to 1 $ft^3$ per second, or 448.83 gal per minute. Commonly used to report the flow of streams.

**SELF-SHOOTER** *See* BOOMING.

**SHAFT FACTOR** A correction factor applied to drill-hole values after a shaft has been sunk over the drill hole. The factor is based on the difference in values obtained from the drill hole and from the shaft; the shaft value is generally considered the more reliable of the two.

**SHELBY TUBE** A split-tube sample collector for hollow-stem augers that allows sampling of soil and clay without significant disturbance.

**SHINGLE** 1. The flatter pebbles and cobbles in a stream deposit will often come to rest with their uppermost edge leaning slightly downstream. This "shingling" effect is used by placer miners to determine the direction of flow of ancient streams, and it can be particularly useful when working drift mines. 2. Beach gravel, especially if consisting of flat or flattish pebbles.

**SHOE FACTOR** *See* DRIVE SHOE FACTOR.

**SHOTTY GOLD** Small granular pieces of gold resembling shot (Fay, 1920). Any small, more or less rounded gold particle that is somewhat equidimensional rather than platy.

**SICK MERCURY** Mercury that is gray and dull on the surface as opposed to silver and shiny. *See* FLOURED MERCURY.

**SKIM BAR** An area near the upstream end of an accretion bar from which superficial concentrations of flood gold are mined by skimming off a thin layer of gravel. They are sometimes known as POINT BARS, probably because of their proximity to the upper point of the accretion bar. *See* FLOOD GOLD; *also* ACCRETION BAR.

**SLACKLINE SCRAPER** Consists essentially of a head tower and a movable tail tower or tail block supporting a track cable. A bucket or scraper running along the track cable can be raised and lowered by tightening or slackening the track cable. The digging bucket or scraper runs out by gravity and is pulled in by a drag cable. The hoisting machinery and in some cases a screening or washing plant are incorporated in the head tower. This arrangement is also known as a CABLEWAY SCRAPER. The SAUERMAN EXCAVATOR is of this type.

**SLATE** A fine-grained rock formed by the compression of clay, shale, etc., that tends to split along parallel cleavage planes and form a rough, platy bedrock and is well-suited for the retention of placer gold where streams cut across dipping beds.

**SLICKENS** A word sometimes used to designate the finer-sized tailings, or mud, discharged from a placer mine. Sometimes synonymous with slime.

**SLUDGE** The fluid mixture of chopped-up core and water that results from the drilling action in a churn drill hole. When the sludge is pumped from the hole, it becomes the sample for the particular section of the hole that produced it.

**SLUICE BOX** An elongated wooden or metal trough, equipped with riffles, through which alluvial material is washed to recover its gold or other heavy minerals. Small sluice boxes are commonly, but erroneously, called LONG TOMS.

**SLUICE PLATE** A shallow, flat-bottomed steel hopper arrangement at the head end of a sluice box. A bulldozer is generally used to push gold-bearing gravel onto the sluiceplate. From there, the gold-bearing gravel is washed into the sluice box by water issuing from a large pipe or by means of a small hydraulic giant.

**SODIUM AMALGAM** Mercury that has been treated with small amounts of metallic sodium to increase its affinity for gold and other metals.

**SPECIFIC GRAVITY** The specific gravity of a substance is its weight as compared with the weight of an equal volume of pure water. For example, gold has a specific gravity of about 19. The specific gravity of a mineral largely determines its susceptibility to recovery in simple gravity concentrators such as sluice boxes.

**SPECIMEN GOLD** Nuggety gold or other forms suitable for the manufacture of natural-gold jewelry or for display purposes.

**SPIRAL CONCENTRATOR** A wet-type gravity concentrator in which a sand/water mixture, flowing down a long, spiral-shaped launder, separates into concentrate and tailing fractions. The concentrates are taken off through ports, while the tailings flow to waste at the bottom. The HUMPHREY'S SPIRAL, which employs this principle, is widely used for recovering heavy minerals from beach sands.

**SPONGE** The somewhat porous mass of gold remaining after the mercury has been removed from a gold amalgam by heating.

**SPOON** A shallow, oblong vessel, at one time made from a section of ox horn but now made of metal. Used to test small samples of gold-bearing material by washing, in a manner similar to panning. More properly called a MINER'S SPOON or HORN SPOON.

**SPOTTED GRAVEL** When gold is erratically distributed through a deposit, the term "spotted" or "spotty" gravel is sometimes applied to it.

**STRIP** To remove the overlying earth, low-grade, or barren material from a placer deposit.

**STRUCK CAPACITY** Level-full, that is, the capacity of a container filled even with its rim or top.

**SUBMARINE PLACER** *See* MARINE PLACER.

**SUCKER** 1. A syringe used to remove material from underwater crevices in the bedrock. 2. A small, handheld jet dredge of the type carried underwater.

**SUCTION DREDGE** *See* HYDRAULIC DREDGE and JET DREDGE.

**SUCTION LIFT** The vertical distance from the level of the water supply to the center of a pump, to which must be added the loss due to friction of the water in the suction pipe.

**SURF WASHER** A small sluice, somewhat similar to a long tom, used to recover gold from beach sands. The surf washer is placed so that the incoming surf rushes up the sluice, washing material from a hopper and, upon retreating, carrying it over the riffles.

**SWELL** The expansion or increase in volume of earth or gravel upon loosening or removal from the ground. The average swell of gravel is around 25 percent and sometimes as high as 50 percent.

**TAIL** (verb) Manipulating the concentrate product in a gold pan in such a way that the heavier minerals, and in particular the gold colors, string out in the bottom of the pan in a long, narrow "tail," where they can be readily inspected or counted. This is referred to as "tailing a pan."

**TERTIARY CHANNELS** Ancient gravel deposits, often auriferous, composed of Tertiary stream alluvium. Tertiary gravels are abundant in the Sierra Nevada gold belt of California, where many have been covered by extensive volcanic eruptions, subsequently elevated by mountain uplifts, and are now found as deeply buried channels, high above the present streambeds.

**TEST PIT** *See* PITTING.

**THAW POINTS** Water pipes driven into frozen gravel, through which water at natural temperature is circulated for weeks or months to thaw the ground ahead of dredging. Where used in Alaska, points are usually spaced 16 ft apart. After thawing, the ground does not freeze again, and thawing is usually carried one or two seasons ahead of the dredge.

**TIGHT GRAVEL** A hard, or compact, gravel that is not cemented but requires greater than normal effort to excavate. Compare with CEMENTED GRAVEL.

**TILL** Non-sorted, non-stratified sediment carried or deposited by a glacier (AGI, 1962).

**TOP WASH** A deposit of gravel found not in a channel on the bedrock, but resting on cement overlying the bottom deposit (Dunn, 1888).

**TRACE** A very small quantity of gold, usually a speck too small to weigh. In reporting samples it is abbreviated "tr."

**TRESTLE SLUICE** A moveable steel sluice constructed on a skid- or track-mounted trestle, usually provided with a hopper, grizzly, and wash water system, and fed by a dragline or similar excavator. Also called an ELEVATED SLUICE.

**TROMMEL** A heavy-duty revolving screen used for washing and removing the rocks or cobbles from placer material prior to treatment in the sluices, gold-saving tables, or other recovery equipment.

**TROY OUNCE** The one-twelfth part of a pound of 5,760 grains; that is, 480 grains. It equals 20 pennyweights, 1.09714 avoirdupois oz, 31.1035 g, or 31,103 mg. This is the ounce designated in all assay returns for gold, silver, or other precious metals (Fay, 1920).

**TUNNEL** The nearly horizontal excavated opening from the surface into the mine (Dunn, 1888).

**UNDERCURRENT** A large, flat, broad branch sluice placed beside and a little lower than the main sluice. This apparatus is riffled like the sluice, but being much wider than the latter, allows the water to spread out in a thin sheet over its surface, thereby so abating the velocity of the current that the very fine gold, including the rusty particles, is more apt to be caught here than in the sluice (Fay, 1920). Undercurrents are usually fed with fine-sized material taken from the main sluice by means of a grizzly placed in the sluice bottom, near the discharge end.

**UPPER LEAD** (pronounced leed) A pay lead in a top wash or in the gravel deposit considerably above the bedrock (Dunn, 1888).

**VOLUME FACTOR** The volume of sample that should be taken into a churn drill casing for each foot of drive. For example, a standard 6-in drive pipe equipped with a new 7½-in drive shoe will theoretically take in a volume of 530 in$^3$, or 0.306 ft$^3$ per foot of drive. *See* CORE FACTOR; DRIVE SHOE FACTOR; and DRILL FACTOR.

**WARD DRILL** A lightweight, hand-powered churn drill widely used in South America, particularly in remote areas where access is difficult and manpower is cheap. The drilling tools are suspended from a tripod and the reciprocating motion provided by a simple spudding arm known as a Diablo. Sometimes referred to as a HAND DRILL.

**WASH** 1. (noun) A western miners' term for any loose surface deposits of sand, gravel, boulders, etc. 2. (noun) The dry bed of an intermittent stream, sometimes at the bottom of a canyon, also called dry wash. 3. (verb) To subject gravel, etc., to the action of water to separate the valuable material from the worthless or less

valuable, as to wash gold (Fay, 1920). In drift mining (California), the term "wash" is used indifferently in the description of channel gravel, volcanic mud flows, or masses of lava boulders (Dunn, 1888).

**WASTE** Valueless material such as barren gravel or overburden. Material too poor to pay for washing.

**WATER TABLE** The upper limit of the portion of the ground wholly saturated with water. This may be very near the surface or many feet below it (Fay, 1920).

**WEATHERING** The group of processes, such as the chemical action of air and rain water and of plants and bacteria and the mechanical action of changes of temperature, whereby rocks on exposure to the weather change in character, decay, and finally crumble into soil (Fay, 1920).

**WING DAM** A dam built partially across a river to deflect the water from its course (Fay, 1920). *See* RIVER MINING.

**WING FENCE** A V-shaped wall, usually made of heavy timber and attached to the head of a sluice and arranged to guide gravel into the sluice as it is swept from the pit by a hydraulic giant.

**YARDAGE** 1. The number of cubic yards of gravel mined or put through a washing plant in a shift or a day. 2. A measured block of gravel.

**YIELD** The quantity or gross value of minerals extracted from a deposit.

**YOUTH** *See* EROSION CYCLES.

**ZIRCON** A mineral having widespread occurrence as small crystals in igneous rocks. Composition: zirconium silicate, $ZrSi0_4$. Because of its resistance to weathering and moderate specific gravity (4.68), zircon is a common constituent of black sands associated with gold placers.

# Appendix B

# Minerals and Related Materials Commonly Found in Placers

## Identification of Minerals Commonly Occurring in Placer Deposits

| Mineral, element, or material | Occurrence potential | Description |
|---|---|---|
| Aluminum | Infrequent | Metallic aluminum; does not occur naturally. Has white oxide coating; color: silver to gray; soft and malleable; often too light to concentrate in a sluice box but is often seen as a coating on steel and rocks from wear of aluminum hose fittings. |
| Amalgam | Common | An alloy of gold and quicksilver and frequently silver; may contain copper; color: silver-white. Usually liquid but may be paste-like if an excess of gold and silver. |
| Amphibole and pyroxene | Common | Both amphiboles and pyroxene have good prismatic cleavages: pyroxene, more square, 87° and 93°; amphiboles, 56° and 124°.<br>a) amphibole group:<br>hornblende—dark green, dark brown, black; vitreous<br>b) pyroxene group - prismatic crystal form:<br>augite—white, pale green, most commonly brown-black or dark green<br>hypersthene—white, pale green, brown-black; vitreous diopside—white, pale green, brown-black; vitreous. |
| Apatite | Common | Hexagonal crystal form; specific gravity 3.15–3.20; hardness-5; color: green, brown, blue, violet, or colorless. |
| Barite | Rare | Heavy spar. Barytes (Barium sulfate). Brittle, hardness 2.5–3.5; specific gravity 4.3–4.6; color: white, also may be yellow, gray, blue, red, brown, or dark brown; transparent to opaque; characterized by high specific gravity, insolubility in acids, and cleavage. |
| Cassiterite | Rare | Tin stone, stream tin, tin ore (tin dioxide). Brittle, hardness 6–7; specific gravity 6.8–7.1; color: brown or black, sometimes red, gray, white, or yellow; distinguished because of high specific gravity, hardness, and infusibility. |
| Cinnabar | Rare | (Mercury sulfide.) Hardness 2–2.5; specific gravity 8; has a metallic luster; color: copper-red. Can be dissolved with 1:1 nitric acid. |
| Copper | Rare | Very ductile and malleable; hardness 2.5–3.0; specific gravity 8.8; metallic luster; color: copper-red; may be more common in lateritic environments (Oregon coast); dissolves in nitric acid. |
| Corundum | Rare | Gem variety sapphire or ruby; color: pastels, white to gray, more rarely blue, green, red, often iridescent; hexagonal, tabular, crystals; vitreous. |
| Galena | Rare | Lead glance (lead sulfide); usually occurs in cubes, either as crystals or cleavage fragments; hardness 2.5; specific gravity 7.5; metallic luster; color: lead-gray; distinguished by color, softness, high specific gravity, and usually cubic cleavage. |

| Mineral, element, or material | Occurrence potential | Description |
|---|---|---|
| Garnet | Common | (Silicates that may contain calcium, magnesium, iron, aluminum, manganese, chromium, or titanium.) May occur in a hexoctahedral crystal form. Brittle to tough when massive; hardness 6.5–7.5; specific gravity 3.1–4.3; resinous luster; color: red, brown, yellow, white, apple-green, black; some bright red and green colors; white when finely powdered. |
| Gold | Common | Very malleable and ductile; hardness 2.5–3; specific gravity 15.6–19.3, depending on amount of impurities; metallic luster; color: gold-yellow, sometimes silver-white, rarely orange-red; usually alloyed with silver in varying amounts; distinguished from pyrite and mica by softness and malleability, high specific gravity, and insolubility in acids; chalcopyrite and pyrite may be confused with gold; they are both brittle and soluble in nitric acid; most commonly occurs as flattened scales in placer deposits. |
| Hematite | Common | (Iron oxide.) Black hematite is most common in placers; massive and rounded; hardness 5.5–6.5; specific gravity 4.9–5.3; color: dark steel-gray, iron-black, or red; streak of cherry red or reddish brown; usually only slightly magnetic. |
| Ilmenite | Infrequent | Occurs in placer as grains; hardness 5–6; specific gravity 4.5–5; somewhat metallic luster; color: iron-black; streak is black to brownish red; very slightly magnetic; usually mixed with magnetite as a black sand. |
| Lead | Common | Color: silver-gray; malleable; cuts easily; naturally occurring elemental lead is rare; bullets are usually slightly deformed or jagged masses; bird shot is usually spherical; placer lead often has a white coating; specific gravity varies with alloys as does the hardness. |
| Machinery Hard Surfacing | Common | Silver flakes. Concoidal fractures; iron alloys high in chrome; specific gravity 5.0; dependent on alloys; extremely hard; a resistant covering applied by welding to wear items on equipment. |
| Magnetite | Common | Magnetic iron ore (iron oxide). Brittle; hardness 5.5–6.5; specific gravity 5; metallic luster; streak, black; octahedral crystals; very strongly magnetic; easily distinguished by being readily attracted by a magnet. |
| Marcasite | Very rare | White iron pyrite (iron sulfide). Brittle, hardness 6–6.5; specific gravity 4.9; metallic luster; color: pale bronze-yellow; streak, grayish or brownish black; lighter color than pyrite. |
| Monazite | Rare | (Cerium, lanthaum, thorium phosphate.) Usually occurs in grains; sometimes flattened; brittle, hardness 5–5.5; specific gravity 4.0–5.3; resinous luster; color: hyacinth-red, clove-brown, reddish or yellowish brown; slightly transparent; common in the Idaho Batholith and many other granitic bodies. |

| Mineral, element, or material | Occurrence potential | Description |
|---|---|---|
| Platinum | Rare | (Alloyed with iron, iridium, rhodium, palladium, etc.) Usually in grains or scales; malleable and ductile; hardness 4–4.5; specific gravity 14–19; when pure, 21–22; metallic luster; color: whitish steel-gray; shiny; occasionally magnetic (if high in iron); distinguished by color, high gravity, malleability, and insolubility in acids. Will be most common in material derived from mafic or ultramafic igneous source rocks. |
| Pyrite | Common | Iron pyrite (iron sulfide). Brittle, hardness 6–6.5; specific gravity 4.9–5.1; metallic, glistening luster; color: pale brass-yellow; streak, greenish black or brownish black; quite often occurs as cubes; concoidal fractures. |
| Pyrrhotite | Rare | Similar to pyrite, but slightly magnetic; crystals are tabular to pyramidal but usually massive. |
| Rutile | Common | (Titanium dioxide.) Brittle, hardness 6–6.5; specific gravity 4.25; metallic luster; color: reddish brown to red, sometimes yellowish, bluish, violet, black; powder, pale brown; tetragonal crystal form. |
| Scheelite | Rare | (Calcium tungstate.) Brittle, hardness 4.5–5; specific gravity 5.9–6.1; color: white, yellowish white, pale yellow, brownish, greenish, reddish; powder, white; will fluoresce metallic blue under short-wave ultraviolet light; most commonly found in skarns. |
| Stibnite | Very rare | Antimonite, antimony glace (antimony trisulfide). Hardness 2; specific gravity 4.5; metallic luster on fresh surface; color: lead-gray; streak, lead-gray. |
| Tourmaline | Rare | (Boron and aluminum silicate.) Brittle, hardness 7–7.5; specific gravity 2.9–3.2; luster, vitreous to resinous; color: most commonly black, brownish black. |
| Welding splatter | Common | Composed of iron compounds, including steel or stainless steel; hardness varies; specific gravity varies; may or may not be magnetic, depending on composition. Usually observed as microscopic spheres. |
| Wolframite | Rare | (Iron, manganese tungstate.) Brittle, hardness 7–7.5; specific gravity 2.9–3.2; luster, vitreous to resinous; color: black, brownish black. |
| Xeonotime | Rare | Yttrium phosphate. Yellow-brown, red-brown, dark brown, flesh red, greyish white, greenish yellow, vitreous to resinous, translucent, opaque, and radioactive; common in the Idaho Batholith. |
| Zircon | Common | (Zirconium silicate.) Brittle, hardness 7.5; specific gravity 4.7; tetragonal crystals; color: colorless, pale yellowish, grayish, yellowish green, brownish yellow, reddish brown; streak, uncolored; fluoresces orange under short-wave ultraviolet light; looks like glass footballs under microscope; very small. |

# Appendix C
# Conversion Tables

# Metric and U.S. Weights and Measures

## Length

Miles x 1.6093 = Kilometers
Yards x 0.9144 = Meters
Feet x 0.3048 = Meters
Feet x 30.48 = Centimeters
Inches x 2.54 = Centimeters
Inches x 25.4 = Millimeters
Kilometers x 0.621 = Miles

Kilometers x 1093.6 = Yards
Kilometers x 3280.9 = Feet
Meters x 1.094 = Yards
Meters x 3.281 = Feet
Meters x 39.37 = Inches
Centimeters x 0.3937 = Inches
Millimeters x 0.03937 = Inches

## Area

Square mile x 2.59 = Square kilometers
Acres x 0.00405 = Square kilometers
Acres x 0.4047 = Hectares
Square yards x 0.8361 = Square meters
Square feet x 0.0929 = Square meters
Square inches x 6.452 = Square centimeters

Square kilometers x 0.3861 = Square miles
Square kilometers x 247.11 = Acres
Hectares x 2.471 = Acres
Square meters x 1.196 = Square yards
Square meters x 10.765 = Square feet
Square centimeters x 0.155 = Square inches
Square millimeters x 0.00155 = Square inches
Square inches x 645.2 = Square millimeters

## Volume

Cubic yards x 0.765 = Cubic meters
Cubic feet x 0.0283 = Cubic meters
Cubic inches x 16.383 = Cubic centimeters

Cubic meters x 36.3145 = Cubic feet
Cubic centimeters x 0.06102 = Cubic inches
Cubic yard x 27 = Cubic feet
Cubic meters x 1.308 = Cubic yards

## Liquid Measure

U.S. gallons x 0.8333 = Imperial gallons
Gallons x 3.785 = Liters
Quarts x 0.946 = Liters

Liters x 0.2642 = Gallons
Liters x 1.057 = Quarts
Cubic feet x 0.1377 = Gallons
Imperial gallons x 1.2009 = U.S. gallons

## Weight

Pounds x 0.453 = Kilograms

Kilograms x 2.2046 = Pounds

# Equivalent Measurements

## Length

1 Mile = 8 Furlongs
= 80 Chains
= 320 Rods
= 1,760 Yards
= 5,280 Feet
1 Furlong = 10 Chains
= 20 Yards
1 Station = 6.06 Rods
= 33.3 Yards
1 Station = 100 Feet
1 Chain = 4 Rods

1 Chain = 122 Yards
= 66 Feet
= 100 Links
1 Rod = 5.5 Yards
= 16.5 Feet
1 Yard = 3 Feet
= 36 Inches
1 Vara = 33 Inches
1 Foot = 12 Inches
1 Link = 7.92 inches
1 Inch = 0.0833 Feet

## Square Measure

1 Township = 36 Square miles
1 Square mile = 1 Section
= 640 Acres
1 Acre = 4,840 Square yards
= 43,560 Square feet
= 10 Square chains
= 160 Square rods

Lode claim = 600 x 1,500 Feet
= 20.661 Acres
= 3306.78 Square rods
Placer claim = 20 Acres/locator
1 Square rod = 272¼ Square feet
1 Square yard = 9 Square feet
1 Square foot = 144 Square inches

## Cubic Measure

1 Cubic yard = 27 Cubic feet
1 Cord (wood) = 4 x 4 x 8 Feet
= 128 Cubic feet
1 Ton (shipping) = 40 Cubic feet

1 Cubic foot = 7.48 U.S. gallons
1 Bushel = 2,150.42 Cubic inches
= 1.244 Cubic feet
1 Gallon = 231 Cubic feet
1 Cubic foot = 1,728 Cubic inches

## Commercial Weights

1 Long ton = 2,240 Pounds
1 Short ton = 2,000 Pounds

1 Pound = 16 Ounces
1 Ounce = 16 Drams
1 Metric tonne = 1.1 Short ton

## Troy Weight (for gold and silver)

1.1035 Grams= 1 Ounce troy
= 20 Pennyweight
= 480 Grains
1 Pennyweight = 24 Grains
= 1.555 Grams
28.350 Grams = 1 ounce avoirdupois

12 Ounce troy = 1 Pound troy
= 0.823 Pounds avoirdupois
= 5,760 Grains
16 Ounce avoirdupois = 1 Pound avoirdupois
= 7,000 Grains
1 Kilogram = 2.2046 Pounds avoirdupois

## Dry Measure

1 Bushel = 32 Quarts
1 Quart = 2 Pints
= 4 Pecks

1 Bushel = 1.2445 Cubic feet
1 Peck = 8 Quarts

## Bucket Volume (standard 5-gallon plastic bucket)

| Inches in Bucket | Volume (cubic feet) |
|---|---|
| 1 | 0.0455 |
| 2 | 0.0910 |
| 3 | 0.1365 |
| 4 | 0.1846 |
| 5 | 0.2326 |
| 6 | 0.2807 |
| 7 | 0.3339 |
| 8 | 0.3872 |
| 9 | 0.4433 |
| 10 | 0.4995 |
| 11 | 0.5558 |
| 12 | 0.6121 |
| 13 | 0.6648 |

# UNITS OF WATER MEASUREMENT

1 Gallon (gal)= 231 Cubic inches
= 0.1331 Cubic feet
1 Gallon of water = 8.33 Pounds
1 Million gallons (m.g.) = 3.0689 Acre feet
1 Cubic foot ($ft^3$)= 1728 Cubic inches
= 7.48 Gallons
1 Cubic foot of water = 62.4 Pounds
1 Acre foot (ac ft)= Amount of water required to cover one acre one foot deep
= 43,560 Cubic feet
= 325,850 Gallons
= 12 acre inches
1 Gallon per minute (gpm)= 0.00223 Cubic feet per second
= 1440 Gallons per day (24 h)
1 Million gallons per 24 hours (m.g./d)= 1.547 Cubic feet per second
= 695 Gallons per minute
1 Cubic foot per second (sec $ft^3$)= 7.48 Gallons per second
= 448.8 Gallons per minute
= 646,272 Gallons per day (24 h)
= 992 acre inch per hour
= 1.983 acre feet per day (24 h)
= 40 Miner's inches (legal value) in Arizona, California, Montana, and Oregon
= 50 Miner's inches (legal value) in Idaho, Kansas, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, and Utah
= 38.4 Miner's inches in Colorado
= 35.7 Miner's inches in British Columbia
1 Miner's inch (mi in)= 11.25 Gallons per minute when equivalent to 1/40 second foot
= 9 Gallons per minute when equivalent to 1/50 second foot
1 Miner's inch/day (24 h) =16,200 Gallons when equivalent to 1/40 second foot
1 Miner's inch/day (24 h) =12,960 Gallons when equivalent to 1/50 second foot

# Appendix D
# Material Properties

Bogart, C.L., 1941, Earth excavation, *in* Peele, Robert, and Church, J.A. (eds.), Mining engineer's handbook (3d ed.): New York, Wiley, v. 1, p. 3-01–3-05.

Table 1. Voids in different soils (D. C. Henny)

| Soil | Percentage of voids | | |
|---|---|---|---|
| | Loose | Compact | Wet-rammed |
| Surface (organic) | 59 | 49 | 44 |
| Fine subsoil | 54 | 43 | 45 |
| Gravel | 42 | 37 | 34 |
| Coarse subsoil | 55 | 49 | 46 |

Table 2. Average weights of soils

| Soil | Condition | Lb per $ft^3$ | Lb per $yd^3$ |
|---|---|---|---|
| Sand | Wet | 122 | 3,294 |
| Sand | Dry | 100 | 2,700 |
| Sand | Packed | 110 | 2,970 |
| Gravel | Wet | 125 | 3,375 |
| Gravel | Dry | 112 | 3,024 |
| Clay | Loose, dry | 70 | 1,890 |
| Clay | In place | 116 | 3,132 |
| Clay | Compressed | 130 | 3,510 |
| Clayey earth | Rolled dry | 110 | 2,970 |
| Mud | Wet | 112 | 3,024 |

Table 3. Slopes and angles of repose

| Kind of earth | Slope of repose | Angle of repose | Kind of earth | Slope of repose | Angle of repose |
|---|---|---|---|---|---|
| Sand, clean, loose | 1.5:1 | 34° | Clay, wet | 3.5:1 | 16° |
| Sand and clay, loose | 1.33:1 | 37° | Rock, hard (riprap) | 1:1 | 45° |
| Sand, wet | 2.5:1 | 22° | Sand, clay, gravel (suction-dredged) | 2:1 | 26° |
| Gravel, clean, loose | 1.33:1 | 37° | River mud (suction-dredged) | 3:1 | 18° |
| Gravel and clay, loose | 1.33:1 | 37° | Gravel and sand on shores, exposed to waves | 7.5:1 | 7.5° |
| Clay, dry, loose | 1.33:1 | 37° | | | |
| Clay, dry, natural | 1:1 | 45° | | | |

Table 4. Interstate Commerce Commission, 1919, Shrinkage of earth in railroad fills, as determined by measurement and by the Rule of Bureau of Valuation, p. 417

| Railway | State | Material | Shrinkage by measurement (%) | Shrinkage by the rule (%) | Method of construction | Volume of excavation ($yd^3$) |
|---|---|---|---|---|---|---|
| Ill Central | Ill. | Dune sand, fine and dry | 8.81 | 9.1 | A | 256,408 |
| Nor & West | — | Light clay, considerable sand, some mica | 8.8–9.7 | 9.1 | C, D | 124,059 |
| Cent. Vt. | R.I. | Fine, dry sand | 7.77 | 9.1 | A | 96,767 |
| Nor & West | — | Some quicksand | 10.3 | 9.1 | C, D | 77,120 |
| So. Pacific | Ore. | Silt and coarse gravel, bottom of large fill | 10.3 | 9.1 | B, C, D | 64,160 |
| Nor & West | — | 60% dry sand | 6.1 | 9.1 | C, D | 44,360 |
| So. Pacific | Ore. | Clayey silt, gravelly in spots | 10.1 | 9.1 | B | 31,660 |
| So. Pacific | Ore. | Cemented material, clayey, mostly cuts; 2.5% rock in fill | 15.1 | 8.6 | E | 26,781 |
| So. Pacific | Ore. | Borrow-pit earth, very clayey | 1.8 | 9.1 | B | 11,016 |
| So. Pacific | Ore. | Clayey silt | 11.1 | 8.7 | A, C | 9,648 |
| So. Pacific | Ore. | Very clayey | 3.5 | 9.1 | C, D | 5,572 |
| Cent Vt. | R.I. | Stiff blue clay | 12.27 | 9.1 | A | 3,047 |

*Note.* A, Unloaded from trestle; B, teams and scrapers; C, steam shovels; D, dump wagons; E, carts and horse-drawn cars, dumped from sides and ends of fills.

Table 5. Swell

| | |
|---|---|
| Gravel | 20–40% |
| Clayey gravel | up to 50% |

# Appendix E
# Field Guide and Checklist

# FIELD GUIDE AND CHECK LIST FOR PLACER INVESTIGATIONS

Revised 8/2003

1. Date of examination ______________________________

2. Name of claim(s) or property ______________________________

______________________________

State ____________ County ____________ District ____________

Township ____________ Range ____________ Section(s) ____________

3. Are the subject lands under a special category designation?

Yes ( ); No ( ). If yes, describe ______________________________

______________________________

4. Reason for examination ______________________________

______________________________

5. Examined by ______________________________

6. Assisted by ______________________________

7. Others present ______________________________

8. Numbers, types and sizes of claims, and total acres ____________

______________________________

______________________________

9. Names of locators and present claim owner ____________

______________________________

______________________________

10. Claim owner address ______________________________

______________________________

______________________________

11. Are claims held or leased by a corporation? Yes ( ); No ( ).

If yes, are shares of the corporation publicly traded?

Yes ( ); No ( ). Remarks ______________________________

______________________________

______________________________

If yes, is there evidence of dummy locators? Yes ( ); No ( ). Remarks ____________

______________________________

12. Types of deposits present (lag, gulch, transport, etc. List all that are appropriate.)

13. Terrain

14. Gradient of deposit: Less than 5% ( ); More than 5% ( ).

Remarks

15. Is the deposit dissected by deep washes or old workings? Yes ( ); No ( ).

Remarks

16. Type and extent of overburden

17. Depth to water table

18. Depth to bedrock

19. Kind of bedrock (rock type)

20. Does bedrock exhibit vertical foliation or other vertical structures?

21. Hardness of bedrock

22. Bedrock slope or contour to be expected

23. Are high bedrock pinnacles or reefs in evidence? Yes ( ); No ( ).

Remarks ______________________________________________

______________________________________________

______________________________________________

24. Gravel is: Well-rounded ( ); Sub-rounded or Sub-angular ( ); Angular ( ).

Remarks______________________________________________

______________________________________________

25. Does gravel contain rocks over 10 inch diameter? Yes ( ); No ( ).

Remarks______________________________________________

______________________________________________

26. Boulders (maximum size, number, distribution, etc.)______________________

______________________________________________

______________________________________________

______________________________________________

27. Estimated percent boulders present: ______________________

Estimated boulder factor (if any) and calculation method______________

______________________________________________

28. Percent swell and calculation method______________________

______________________________________________

______________________________________________

29. Rock types noted in gravel______________________

______________________________________________

______________________________________________

30. Predominant rock types______________________

______________________________________________

31. Sand (kind, amount, distribution, etc.)______________________

______________________________________________

______________________________________________

______________________________________________

32. Sorting or bedding patterns (if apparent)______________________

______________________________________________

33. Sticky clay? Yes ( ); No ( ). Remarks______________________________

______________________________

______________________________

34. Cemented gravel? Yes ( ); No ( ). Remarks, including type of cement ________

______________________________

______________________________

35. Caliche? Yes ( ); No ( ). Remarks______________________________

______________________________

______________________________

36. Permafrost? Yes ( ); No ( ). Remarks______________________________

______________________________

37. Buried timber? Yes ( ); No ( ). Remarks______________________________

______________________________

38. Hard or abrasive digging conditions? Yes ( ); No ( ). Remarks____________

______________________________

______________________________

39. Character of gold: Coarse ( ); Flaky ( ); Fine ( ); Rough ( );

Shotty ( ); Smooth ( ); Bright ( ); Stained or coated ( ).

Remarks______________________________

______________________________

______________________________

40. Can good recovery be expected by use of riffles or jigs? Yes ( ); No ( ).

Remarks______________________________

______________________________

41. Is recovery said to depend on a secret process or special equipment?

Yes ( ); No ( ). Remarks______________________________

______________________________

______________________________

42. Are black sands said to contain locked gold values? Yes ( ); No ( ).

If Yes, is crushing black sand said to be required? Yes ( ); No ( ).

Remarks________________________________________________________________

43. Are black sands or other concentrates said to contain platinum, palladium, or other platinum group elements? Yes ( ); No ( ).

If yes, check: Pt ( ); Pd ( ); Ru ( ); Rh ( ); Os ( ); Ir ( ).

Remarks________________________________________________________________

44. Are black sands or other concentrates said to contain rare earth elements or other valuable materials? Yes ( ); No ( ). Remarks__________________________

45. Have black sands been checked for valuable minerals other than gold? Yes ( ); No ( ). If Yes, note by whom and the laboratories.

Remarks________________________________________________________________

46. Are only specific laboratories said to be capable of finding precious metals in the concentrates or the deposit? Yes ( ); No ( ).

Reasons, methods, and laboratories if Yes________________________________

47. Distribution of values in deposit (if known)______________________________

48. Record or evidence of previous sampling________________________________

49. Results, sources and methods of prior sampling (if known)____________________

50. If previous sample results are available, how are they reported?

( ) Ounces per bank cubic yard
( ) Ounces per loose cubic yard

( ) Dollars per bank cubic yard
( ) Dollars per loose cubic yard

( ) Ounces per ton of concentrates
( ) Dollars per ton of concentrates

( ) Ounces per ton of an unspecified reference weight or volume

( ) Other, specify:____________________

Remarks____________________

51. Is there an average fineness reported for this deposit, drainage, or district?

52. Is there a gold particle size distribution reported for this deposit, drainage, or distr

53. Are old workings evident? Yes ( ); No ( ). Surface or underground?

Remarks____________________

54. Past production, if known, and data source ____________________

55. Date of last production or work____________________

56. Reason for termination of past production or work____________________

57. Present work (if any)

58. Applicable mining method(s)

59. Possible startup cost (and source) to bring property into production

60. Possible mining cost, and source of information

61. Dimensions of (physically) mineable ground

62. Possible extensions

63. Maximum yardage or resources indicated to date

64. Mining equipment on ground, including condition and ownership

65. Accessory equipment or improvements on ground________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

66. Water supply________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

67. Does claim owner, lessee, or operator possess a legal surface or subsurface water right? Yes ( ); No ( ). Remarks ________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

68. Electric power supply: Voltage? _______ Three phase available? ________

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

69. Does property have adequate storage for washed gravels and overburden? Yes ( ); No ( ). Remarks ________________________________

________________________________________________________________

________________________________________________________________

70. Would mining in this area come under County, State or Federal water quality con authority (including the Army Corps of Engineers)?
Yes ( ); No ( ). Remarks ________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

71. Do Fish and Game regulations apply? Yes ( ); No ( ). Remarks____________

________________________________________________________________

72. Can settling ponds be built to effectively retain or clarify muddy process water? Yes ( ); No ( ). Remarks, including suitable locations______________________

_______________________________________________

_______________________________________________

73. Can bedrock drains or filters be built to effectively filter muddy or excess water? Yes ( ); No ( ). Remarks, including appropriate depth and gradient __________

_______________________________________________

_______________________________________________

74. Will the existing streambed need to be relocated before mining can take place? Yes ( ); No ( ). Remarks______________________________

_______________________________________________

_______________________________________________

75. Has the claim owner, lessee, or operator produced an acceptable mining and reclamation plan? Yes ( ); No ( ). Remarks______________________

_______________________________________________

_______________________________________________

76. Is property subject to special category land requirements for reclamation, revegetation, or other surface issues? Yes ( ); No ( ). Remarks__________

_______________________________________________

_______________________________________________

_______________________________________________

77. Are there any Notices of Noncompliance, Cease and Desist Orders, judgments, or any liens outstanding against the property? Yes ( ); No ( ).

Remarks _______________________________________

_______________________________________________

_______________________________________________

_______________________________________________

78. Has a residence been constructed or placed on the property or claim? Yes ( ); No ( ). If Yes, have all appropriate permits and authorizations been obtained and are they current? Yes ( ); No ( ). Remarks and dates issued

_______________________________________________

_______________________________________________

79. Are millsite claims associated or related? Yes ( ); No ( ). Remarks__________

80. Elevation of property__________

81. Climate__________

82. Working season dates__________

83. Season governed by__________

84. Surface cover and its effect on mining__________

85. Merchantable timber or other surface values__________

86. Nearest town__________

87. Access__________

88. Reference maps__________

89. Aerial photos (USGS, BLM, Soil Conservation Service, Forest Service, etc.)__________

90. Reference literature__________

91. Previous examinations or reports, and sources__________

92. Other reference sources ______________________________

______________________________

______________________________

93. Your sampling (describe or attach notes) ______________________________

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94. Additional information and remarks ______________________________

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95. Attach suitable map or sketches (if needed) ______________________________

96. Attach photographs of pertinent features (if available).

97. Additional information, as applicable.

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**Adapted from Placer Examination, Principles and Practice, BLM Technical Bulletin 4, by John H. Wells, 1969, Rev. 1989.**
**Updated 8/1999, 3/2000, 8/2001, and 8/2003 by Matthew W. Shumaker.**
Not every item will apply in every situation. Permafrost is rarely an issue in desert areas. However, all items should be considered.

# Appendix F
# Value Relationships

Value relationships between sample size and gold particle weights, assuming one gold particle per sample and a price of $350 per troy ounce.

| Gold particle weight (g) | Value of particle ($) | Sample size (cubic yards) 0.005 | 0.0075 | 0.01 | 0.025 | 0.05 | 0.075 | 0.1 | 0.25 | 0.5 | 0.75 | 1 | 2 | 5 | 10 | 20 | 50 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dollar value per cubic yard | | | | | | | | | | | | | | | | |
| 0.001 | 0.011 | 2.251 | 1.500 | 1.125 | 0.450 | 0.225 | 0.150 | 0.113 | 0.045 | 0.023 | 0.015 | 0.011 | 0.006 | 0.002 | 0.001 | 0.001 | | |
| 0.002 | 0.023 | 4.501 | 3.001 | 2.251 | 0.900 | 0.450 | 0.300 | 0.225 | 0.090 | 0.045 | 0.030 | 0.023 | 0.011 | 0.005 | 0.002 | 0.001 | | |
| 0.003 | 0.034 | 6.752 | 4.501 | 3.376 | 1.350 | 0.675 | 0.450 | 0.338 | 0.135 | 0.068 | 0.045 | 0.034 | 0.017 | 0.007 | 0.003 | 0.002 | 0.001 | |
| 0.004 | 0.045 | 9.002 | 6.002 | 4.501 | 1.800 | 0.900 | 0.600 | 0.450 | 0.180 | 0.090 | 0.060 | 0.045 | 0.023 | 0.009 | 0.005 | 0.002 | 0.001 | |
| 0.005 | 0.056 | 11.253 | 7.502 | 5.626 | 2.251 | 1.125 | 0.750 | 0.563 | 0.225 | 0.113 | 0.075 | 0.056 | 0.028 | 0.011 | 0.006 | 0.003 | 0.001 | 0.001 |
| 0.006 | 0.068 | 13.504 | 9.002 | 6.752 | 2.701 | 1.350 | 0.900 | 0.675 | 0.270 | 0.135 | 0.090 | 0.068 | 0.034 | 0.014 | 0.007 | 0.003 | 0.001 | 0.001 |
| 0.007 | 0.079 | 15.754 | 10.503 | 7.877 | 3.151 | 1.575 | 1.050 | 0.788 | 0.315 | 0.158 | 0.105 | 0.079 | 0.039 | 0.016 | 0.008 | 0.004 | 0.002 | 0.001 |
| 0.008 | 0.090 | 18.005 | 12.003 | 9.002 | 3.601 | 1.800 | 1.200 | 0.900 | 0.360 | 0.180 | 0.120 | 0.090 | 0.045 | 0.018 | 0.009 | 0.005 | 0.002 | 0.001 |
| 0.009 | 0.101 | 20.255 | 13.504 | 10.128 | 4.051 | 2.026 | 1.350 | 1.013 | 0.405 | 0.203 | 0.135 | 0.101 | 0.051 | 0.020 | 0.010 | 0.005 | 0.002 | 0.001 |
| 0.010 | 0.113 | 22.506 | 15.004 | 11.253 | 4.501 | 2.251 | 1.500 | 1.125 | 0.450 | 0.225 | 0.150 | 0.113 | 0.056 | 0.023 | 0.011 | 0.006 | 0.002 | 0.001 |
| 0.020 | 0.225 | 45.012 | 30.008 | 22.506 | 9.002 | 4.501 | 3.001 | 2.251 | 0.900 | 0.450 | 0.300 | 0.225 | 0.113 | 0.045 | 0.023 | 0.011 | 0.005 | 0.002 |
| 0.030 | 0.338 | 67.518 | 45.012 | 33.759 | 13.504 | 6.752 | 4.501 | 3.376 | 1.350 | 0.675 | 0.450 | 0.338 | 0.169 | 0.068 | 0.034 | 0.017 | 0.007 | 0.003 |
| 0.040 | 0.450 | 90.023 | 60.016 | 45.012 | 18.005 | 9.002 | 6.002 | 4.501 | 1.800 | 0.900 | 0.600 | 0.450 | 0.225 | 0.090 | 0.045 | 0.023 | 0.009 | 0.005 |
| 0.050 | 0.563 | 112.529 | 75.020 | 56.265 | 22.506 | 11.253 | 7.502 | 5.626 | 2.251 | 1.125 | 0.750 | 0.563 | 0.281 | 0.113 | 0.056 | 0.028 | 0.011 | 0.006 |
| 0.060 | 0.675 | 135.035 | 90.023 | 67.518 | 27.007 | 13.504 | 9.002 | 6.752 | 2.701 | 1.350 | 0.900 | 0.675 | 0.338 | 0.135 | 0.068 | 0.034 | 0.014 | 0.007 |
| 0.070 | 0.788 | 157.541 | 105.027 | 78.771 | 31.508 | 15.754 | 10.503 | 7.877 | 3.151 | 1.575 | 1.050 | 0.788 | 0.394 | 0.158 | 0.079 | 0.039 | 0.016 | 0.008 |
| 0.080 | 0.900 | 180.047 | 120.031 | 90.023 | 36.009 | 18.005 | 12.003 | 9.002 | 3.601 | 1.800 | 1.200 | 0.900 | 0.450 | 0.180 | 0.090 | 0.045 | 0.018 | 0.009 |
| 0.090 | 1.013 | 202.553 | 135.035 | 101.276 | 40.511 | 20.255 | 13.504 | 10.128 | 4.051 | 2.026 | 1.350 | 1.013 | 0.506 | 0.203 | 0.101 | 0.051 | 0.020 | 0.010 |
| 0.100 | 1.125 | 225.059 | 150.039 | 112.529 | 45.012 | 22.506 | 15.004 | 11.253 | 4.501 | 2.251 | 1.500 | 1.125 | 0.563 | 0.225 | 0.113 | 0.056 | 0.023 | 0.011 |
| 0.150 | 1.688 | 337.588 | 225.059 | 168.794 | 67.518 | 33.759 | 22.506 | 16.879 | 6.752 | 3.376 | 2.251 | 1.688 | 0.844 | 0.338 | 0.169 | 0.084 | 0.034 | 0.017 |
| 0.200 | 2.251 | 450.117 | 300.078 | 225.059 | 90.023 | 45.012 | 30.008 | 22.506 | 9.002 | 4.501 | 3.001 | 2.251 | 1.125 | 0.450 | 0.225 | 0.113 | 0.045 | 0.023 |
| 0.250 | 2.813 | 562.647 | 375.098 | 281.323 | 112.529 | 56.265 | 37.510 | 28.132 | 11.253 | 5.626 | 3.751 | 2.813 | 1.407 | 0.563 | 0.281 | 0.141 | 0.056 | 0.028 |
| 0.300 | 3.376 | 675.176 | 450.117 | 337.588 | 135.035 | 67.518 | 45.012 | 33.759 | 13.504 | 6.752 | 4.501 | 3.376 | 1.688 | 0.675 | 0.338 | 0.169 | 0.068 | 0.034 |
| 0.350 | 3.939 | 787.705 | 525.137 | 393.853 | 157.541 | 78.771 | 52.514 | 39.385 | 15.754 | 7.877 | 5.251 | 3.939 | 1.969 | 0.788 | 0.394 | 0.197 | 0.079 | 0.039 |
| 0.400 | 4.501 | 900.235 | 600.156 | 450.117 | 180.047 | 90.023 | 60.016 | 45.012 | 18.005 | 9.002 | 6.002 | 4.501 | 2.251 | 0.900 | 0.450 | 0.225 | 0.090 | 0.045 |
| 0.450 | 5.064 | 1012.764 | 675.176 | 506.382 | 202.553 | 101.276 | 67.518 | 50.638 | 20.255 | 10.128 | 6.752 | 5.064 | 2.532 | 1.013 | 0.506 | 0.253 | 0.101 | 0.051 |

Value relationships between sample size and gold particle weights, assuming one gold particle per sample and a price of $350 per troy ounce.

| Gold particle weight (g) | Value of particle ($) | Sample size (cubic yards) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.005 | 0.0075 | 0.01 | 0.025 | 0.05 | 0.075 | 0.1 | 0.25 | 0.5 | 0.75 | 1 | 2 | 5 | 10 | 20 | 50 | 100 |
| | | Dollar value per cubic yard | | | | | | | | | | | | | | | | |
| 0.500 | 5.626 | 1125.293 | 750.196 | 562.647 | 225.059 | 112.529 | 75.020 | 56.265 | 22.506 | 11.253 | 7.502 | 5.626 | 2.813 | 1.125 | 0.563 | 0.281 | 0.113 | 0.056 |
| 0.550 | 6.189 | 1237.823 | 825.215 | 618.911 | 247.565 | 123.782 | 82.522 | 61.891 | 24.756 | 12.378 | 8.252 | 6.189 | 3.095 | 1.238 | 0.619 | 0.309 | 0.124 | 0.062 |
| 0.600 | 6.752 | 1350.352 | 900.235 | 675.176 | 270.070 | 135.035 | 90.023 | 67.518 | 27.007 | 13.504 | 9.002 | 6.752 | 3.376 | 1.350 | 0.675 | 0.338 | 0.135 | 0.068 |
| 0.650 | 7.314 | 1462.881 | 975.254 | 731.441 | 292.576 | 146.288 | 97.525 | 73.144 | 29.258 | 14.629 | 9.753 | 7.314 | 3.657 | 1.463 | 0.731 | 0.366 | 0.146 | 0.073 |
| 0.700 | 7.877 | 1575.411 | 1050.274 | 787.705 | 315.082 | 157.541 | 105.027 | 78.771 | 31.508 | 15.754 | 10.503 | 7.877 | 3.939 | 1.575 | 0.788 | 0.394 | 0.158 | 0.079 |
| 0.750 | 8.440 | 1687.940 | 1125.293 | 843.970 | 337.588 | 168.794 | 112.529 | 84.397 | 33.759 | 16.879 | 11.253 | 8.440 | 4.220 | 1.688 | 0.844 | 0.422 | 0.169 | 0.084 |
| 0.800 | 9.002 | 1800.469 | 1200.313 | 900.235 | 360.094 | 180.047 | 120.031 | 90.023 | 36.009 | 18.005 | 12.003 | 9.002 | 4.501 | 1.800 | 0.900 | 0.450 | 0.180 | 0.090 |
| 0.850 | 9.565 | 1912.999 | 1275.332 | 956.499 | 382.600 | 191.300 | 127.533 | 95.650 | 38.260 | 19.130 | 12.753 | 9.565 | 4.782 | 1.913 | 0.956 | 0.478 | 0.191 | 0.096 |
| 0.900 | 10.128 | 2025.528 | 1350.352 | 1012.764 | 405.106 | 202.553 | 135.035 | 101.276 | 40.511 | 20.255 | 13.504 | 10.128 | 5.064 | 2.026 | 1.013 | 0.506 | 0.203 | 0.101 |
| 0.950 | 10.690 | 2138.057 | 1425.372 | 1069.029 | 427.611 | 213.806 | 142.537 | 106.903 | 42.761 | 21.381 | 14.254 | 10.690 | 5.345 | 2.138 | 1.069 | 0.535 | 0.214 | 0.107 |
| 1.000 | 11.253 | 2250.587 | 1500.391 | 1125.293 | 450.117 | 225.059 | 150.039 | 112.529 | 45.012 | 22.506 | 15.004 | 11.253 | 5.626 | 2.251 | 1.125 | 0.563 | 0.225 | 0.113 |
| 2.000 | 22.506 | 4501.174 | 3000.782 | 2250.587 | 900.235 | 450.117 | 300.078 | 225.059 | 90.023 | 45.012 | 30.008 | 22.506 | 11.253 | 4.501 | 2.251 | 1.125 | 0.450 | 0.225 |
| 3.000 | 33.759 | 6751.760 | 4501.174 | 3375.880 | 1350.352 | 675.176 | 450.117 | 337.588 | 135.035 | 67.518 | 45.012 | 33.759 | 16.879 | 6.752 | 3.376 | 1.688 | 0.675 | 0.338 |
| 4.000 | 45.012 | 9002.347 | 6001.565 | 4501.174 | 1800.469 | 900.235 | 600.156 | 450.117 | 180.047 | 90.023 | 60.016 | 45.012 | 22.506 | 9.002 | 4.501 | 2.251 | 0.900 | 0.450 |
| 5.000 | 56.265 | 11252.934 | 7501.956 | 5626.467 | 2250.587 | 1125.293 | 750.196 | 562.647 | 225.059 | 112.529 | 75.020 | 56.265 | 28.132 | 11.253 | 5.626 | 2.813 | 1.125 | 0.563 |
| 6.000 | 67.518 | 13503.521 | 9002.347 | 6751.760 | 2700.704 | 1350.352 | 900.235 | 675.176 | 270.070 | 135.035 | 90.023 | 67.518 | 33.759 | 13.504 | 6.752 | 3.376 | 1.350 | 0.675 |
| 7.000 | 78.771 | 15754.107 | 10502.738 | 7877.054 | 3150.821 | 1575.411 | 1050.274 | 787.705 | 315.082 | 157.541 | 105.027 | 78.771 | 39.385 | 15.754 | 7.877 | 3.939 | 1.575 | 0.788 |
| 8.000 | 90.023 | 18004.694 | 12003.129 | 9002.347 | 3600.939 | 1800.469 | 1200.313 | 900.235 | 360.094 | 180.047 | 120.031 | 90.023 | 45.012 | 18.005 | 9.002 | 4.501 | 1.800 | 0.900 |
| 9.000 | 101.276 | 20255.281 | 13503.521 | 10127.640 | 4051.056 | 2025.528 | 1350.352 | 1012.764 | 405.106 | 202.553 | 135.035 | 101.276 | 50.638 | 20.255 | 10.128 | 5.064 | 2.026 | 1.013 |
| 10.000 | 112.529 | 22505.868 | 15003.912 | 11252.934 | 4501.174 | 2250.587 | 1500.391 | 1125.293 | 450.117 | 225.059 | 150.039 | 112.529 | 56.265 | 22.506 | 11.253 | 5.626 | 2.251 | 1.125 |
| 11.000 | 123.782 | 24756.454 | 16504.303 | 12378.227 | 4951.291 | 2475.645 | 1650.430 | 1237.823 | 495.129 | 247.565 | 165.043 | 123.782 | 61.891 | 24.756 | 12.378 | 6.189 | 2.476 | 1.238 |
| 12.000 | 135.035 | 27007.041 | 18004.694 | 13503.521 | 5401.408 | 2700.704 | 1800.469 | 1350.352 | 540.141 | 270.070 | 180.047 | 135.035 | 67.518 | 27.007 | 13.504 | 6.752 | 2.701 | 1.350 |
| 13.000 | 146.288 | 29257.628 | 19505.085 | 14628.814 | 5851.526 | 2925.763 | 1950.509 | 1462.881 | 585.153 | 292.576 | 195.051 | 146.288 | 73.144 | 29.258 | 14.629 | 7.314 | 2.926 | 1.463 |
| 14.000 | 157.541 | 31508.215 | 21005.476 | 15754.107 | 6301.643 | 3150.821 | 2100.548 | 1575.411 | 630.164 | 315.082 | 210.055 | 157.541 | 78.771 | 31.508 | 15.754 | 7.877 | 3.151 | 1.575 |
| 15.000 | 168.794 | 33758.801 | 22505.868 | 16879.401 | 6751.760 | 3375.880 | 2250.587 | 1687.940 | 675.176 | 337.588 | 225.059 | 168.794 | 84.397 | 33.759 | 16.879 | 8.440 | 3.376 | 1.688 |
| 16.000 | 180.047 | 36009.388 | 24006.259 | 18004.694 | 7201.878 | 3600.939 | 2400.626 | 1800.469 | 720.188 | 360.094 | 240.063 | 180.047 | 90.023 | 36.009 | 18.005 | 9.002 | 3.601 | 1.800 |

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## Related Publications from the Montana Bureau of Mines and Geology

SP 106, Montana placer mining BMPs (Best Management Practices): guidelines for planning, erosion control, and reclamation, McCulloch, R.B., Ihle, B., Ciliberti, V., Williams, D., Mason, M., Potts, S., and Lyon, J., 1993, 32 p.

R 6, Gold placers of Montana, Lyden, C.J., 1948 (reprinted 1987), 120 p.

M 52, Metallic mineral deposits of Lewis and Clark County, Montana, McClernan, H.G., 1983, 73 p.

B 98, Metallic mineral deposits of Powell County, Montana, McClernan, H.G., 1976, 69 p.

B 16, Mines and mineral deposits (except fuels), Jefferson County, Montana, Roby, R.N., Ackerman, W.C., Fulkerson, F.B., and Crowley, F.A., 1960, 120 p.